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The Uganda Section of the Western Rift

By K. A. DAVIES

ABSTRACT

Geological work and drilling in the Western Uganda Rift since 1939 points wholly to the formation of this feature by gradual sinking of the floor. No evidence of compression has been obtained.

THE mode of formation of the Great Rift Valley of Africa has been a subject of continual interest to geologists, especially since the later years of the nineteenth century, when Gregory described in detail the main characteristics of this remarkable feature of the earth's crust. From time to time new facts which throw light on the problem of its formation are accumulated, and the history of events which led to the present trench-like feature can be more clearly discerned.

During the past eleven years a good deal of work has been carried out by the Uganda Geological Survey in the portion of the western rift which bounds the western side of the Protectorate, and it is at the suggestion of Professor Holmes that the present writer sets down the evidence gained from these operations and the conclusions to be drawn from them.

The writer himself must disclaim an intimate field knowledge of this part of the Protectorate, for most of his mapping work was carried out in the eastern part of the country; nevertheless, he has had many opportunities of visiting the western rift to observe and guide the drilling and survey work which has been carried out there over the period mentioned.

The material for this paper has been provided by drilling and geophysical work and by surveys by field geologists of the writer's department. It is from these geologists that most of the evidence comes, though the writer himself, however, must claim full responsibility for the interpretation of the data available.

To obtain a proper appreciation of the Rift Valley structure it is necessary to know something of the older rocks which lie along the sides of the depression and which have been downfaulted to form its floor. These ancient rocks include the Basement Complex proper, the Toro System, and the Karagwe-Ankolean System. Where the Toro

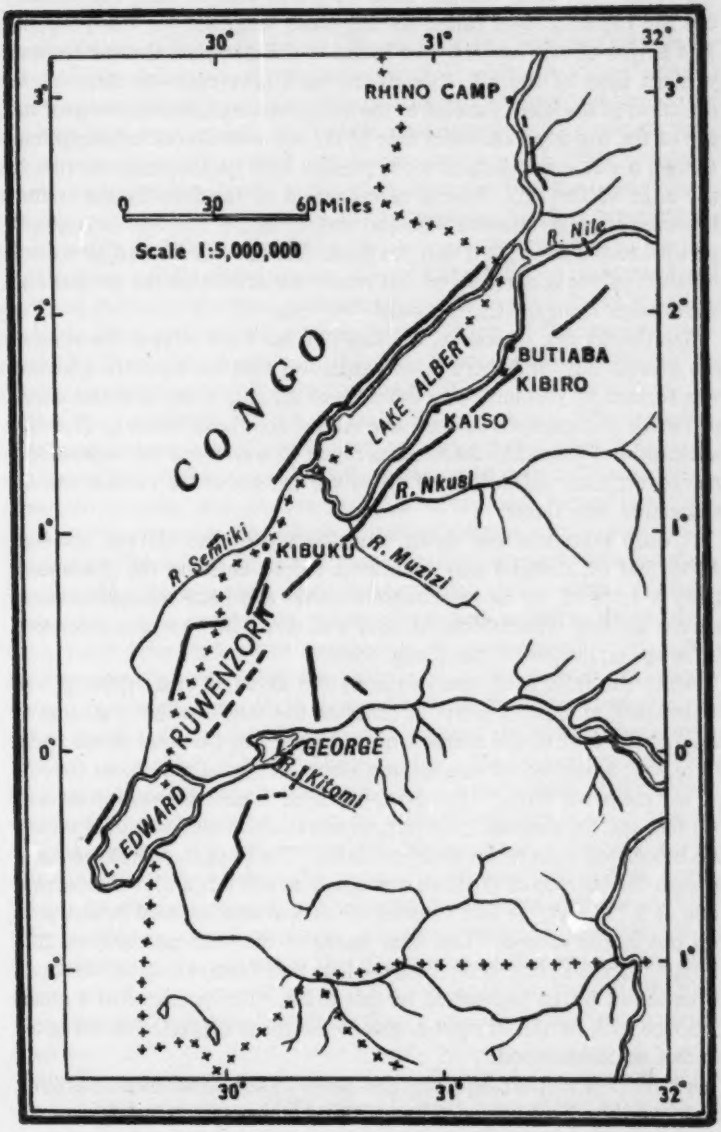
System is typically developed to the south of Lake Albert, it is a well-defined metamorphic series of granulites, gneisses, amphibolites, quartzites, and highly plicated schists. Its relationship to the Basement Complex of the north end of the lake with its kyanite- and graphite-schists, and charnockitic rocks, however, is not certain, though the suggestion is that the Toro System is younger. The Karagwe-Ankolean, which is the youngest of these groups, consists mainly of shales, mudstones, and quartzites, and only exhibits a high degree of metamorphism where it is in contact with granite.

The floor of the rift was covered initially by the Kisegi sandstone series, a largely arenaceous group, followed by a dominantly clay, shale, and sand group called the Kaiso Series. These new beds were laid down, according to Wayland, from the late Pliocene onwards.

In order to simplify the description of the features of the Uganda rift the writer has divided it into sections, beginning with the most northerly.

The Northern End of Lake Albert.—The Lake Albert section of the rift has been described by Shand as a disappointing feature of relatively insignificant proportions. Certainly, viewed from the only road on the eastern side, which was the point at which that writer observed the depression, the eastern wall is only about a thousand feet in height and fades rapidly away to the north to the line of the Victoria Nile. To the south, however, the scarp is some 1,800 feet in height, but even then is far overtopped on the Congo side, where the western slopes descend in places some 4,000 feet in 2½ miles. A full appreciation of the magnitude of the feature, however, is only obtained when consideration is given to the degree of vertical movement of what is now the basement floor of the trough.

In 1938 and 1939 drilling was undertaken at points near the base of the eastern Lake Albert scarp with the object of determining the oil bearing potentialities of the Plio-Pleistocene beds which lie at the bottom of the Rift over this Section. The Lake Albert trough itself runs in a north-easterly–south-westerly direction, and excepting in the north-east corner of the depression and around the mouth of the Semliki the Kaiso-Kisegi beds are largely covered by water. They form in the north-east, however, a triangular piece of dry ground whose lakeward and longest side runs roughly north–south and has a length of some 40 miles. Drilling operations were carried out at the southern end of this piece of dry land and just south of the road which runs to the lake port of Butiaba. A dome-shaped hill at Waki, 2,000 yards from the foot of the scarp at this point, was chosen for the site of the operations, because it was thought that the form might indicate a structure of this nature in the sediments. Shallow ($<$ 500 feet) bores were first put down across the hill both at right-angles and parallel to



Map of the Western Uganda Rift, showing the position of the principal lakes and rivers and of the Ruwenzori Range. Thick lines indicate Plio-Pleistocene faults.

the scarp. No good marker beds were encountered near the surface, but the top of a layer called the Big Sand was used for this purpose. The height of this horizon was found to fall away on the eastern and western sides of the hill, though the sand gave place to clays in the direction of the lake. Parallel to the scarp, however, the fall away of the top of the Big Sand on either side of the hill was almost imperceptible, though a dome was judged to be present with its long axis parallel to the edge of the rift. Recent examination of the logs by the writer, however, suggests that the Big Sand was nothing more than a sandbank parallel to the shore, and that the dome-like hill was formed by a combination of the occurrence of this coarse material near the surface and the erosion from the scarp towards the lake.

Sandbanks are, of course, a feature of the Lake Albert shoreline at the present day, and there is no suggestion that the dome in question was formed by pressure from the sides of the rift. Careful examination of the air photographs of the Lake Albert area have failed to give any indication of dome-like features, as might be seen from the vegetation ; moreover, such indications of oil as are known at the surface are all associated with faults.

A deep bore-hole put down near the top of the hill ran through 4,045 feet of Kisegi-Kaiso sediments before entering the Basement. Only a trace of oil was encountered, and the beds themselves were almost entirely unconsolidated until well down in what was presumed to be the equivalent of the Kisegi Series.

After the failure of operations in the Butiaba area, drilling was undertaken at a point some 11 miles to the south, where the strip of land at the foot of the scarp is often only a few hundred yards wide. Here, too, a marked oil seepage and a hot salt spring occur near the line of the main rift fault. Nine bore-holes, of which the shallowest was 351 feet and the deepest 2,245 feet, were put down, and two of these cut the brecciated zone of the main rift fault. The fault in one of the holes nearest the outcrop of the fault was struck at 428 feet and in the deepest hole at 2,238 feet. A fair amount of oil was encountered in the first, but not in the second. The fault hades to the west generally at 25°, though there is a suggestion from the logs that there is a certain amount of variation in the inclination of this plane. The presence of a small anticline with its axis at right-angles to the rift is suggested in the notes on this neighbourhood.

A bore-hole was subsequently put down by the departmental drilling section on the bank of the Nile at Rhino Camp, some 50 miles north of the northern end of the lake. At this point on the Nile Basement Complex rocks occur on the right bank and some 4 miles east of the bore-hole. Wayland has suggested that at this point an extension of the rift faults runs along this east side of the river, and this appears to

be the case. The bore-hole was stopped at 702 feet, where it was still in unconsolidated clays and sands. The evidence from the left bank, where further drilling was done, shows that the sediments become progressively thinner, to a point 15 miles west of Rhino Camp, where the Basement comes in. A slight north–south scarp occurs at this spot, but may be a purely erosional feature. Insufficient drilling was carried out, however, to discover if there were north–south faults evident anywhere on this west bank. It is certain, however, that the Lake Albert rift was continued at its northern end by a much narrower depression, which was broken by a straight line fault on its eastern side.

About the middle of the eastern side of Lake Albert a wide patch of dry land occurs at the foot of the scarp, which is notable for the fact that it is the type area of the Kaiso Series. Some of the specimens of softer sediments obtained from this area show remarkable slumping effects, suggesting a rapidly sinking lake floor.

The Nkussi-Muzizi Section.—Two rivers join Lake Albert at the south-east corner, which are of considerable interest when judged in relationship to the history of the rift. Running on gradually converging westward courses the northernmost is called the Nkussi and the southern the Muzizi. The distance between them along the scarp is of the order of 14 miles. These two rivers are remarkable for the fact that for considerable distances along their courses narrow strips of sandstone occur. These strips run exactly along the line of the streams, and the present river bed is cut largely into the arenaceous rocks. The sandstones have been closely examined by R. C. Pargeter in the Nkussi valley, up which they run to a point at least 7½ miles from the rift valley scarp. The same observer has pointed out there are at least 330 feet of sandstones in the Nkussi valley. No examination has yet been possible, owing to its inaccessibility, of the mouth of the gorge, where the river debouches on to the Albert flats, but it appears from air photographs that the base of the sandstones is at approximately 500 feet below the level of the surface of immediately pre-rift times. The rocks are very compact and often finely laminated sandstones with very subsidiary conglomerates, and show generally no dip along the thalweg of the stream. The beds, on the other hand, have dips of up to 10° near to and away from the north and south walls of the sedimentary basin, but these flatten out towards the line of the stream.

Similar sandstones are known in the Muzizi for at least 25 miles upstream from the edge of the rift, and these were called by Wayland the Muzizi Sandstones. These are also flat-bedded and equally tough and compact, but where they outcrop are rather more conglomeratic than the sediments of the Nkussi. It is clear from their compactness and for other reasons which need not be enumerated here, that they

must represent the equivalent of beds well down in the Kisegi formation. Comparison with the logs of the bore-hole at the Waki dome suggests that the Nkussi-Muzizi sandstones cannot be the equivalent of anything above the 3,000-ft. level in that hole, and are probably a good deal earlier. It is the writer's opinion, however, that the Albertine sediments are probably deepest at the southern end of the lake, where the first subsidence took place.

It would appear, therefore, from the evidence above, that the downward movement of the floor of the rift was halted at a point 500–600 feet below the original level and the depression was filled up with sediments which backed up the mature pre-rift valleys of the Nkussi and Muzizi. Any lateral pressure which might be postulated to continue after the initiation of the rifting would therefore be indicated in these striking occurrences of sandstones on the immediate eastern side of the rift. It is clear from the evidence in these streams that not the slightest sign of pressure on the flank is indicated.

North Ruwenzori Nose Section.—The main wall of the rift between the Nkussi and the Muzizi continues south to a section where it is some 7 miles east of and parallel to the northern nose of Ruwenzori, and is finally lost beyond in high land. It is separated from the Ruwenzori nose by a north-facing embayment filled with Kisegi and Kaiso sediments. Slab-like pieces of country lying against the main fault near the mouth of the Muzizi suggest a parallel system of fracture which gave rise to a step effect on the side of the rift.

Ruwenzori itself is composed, largely at any rate, of rocks of the Toro System, which show very tight folding and often intense shearing. The linear factor now present and induced by these movements is normally of a direction, both in the mountain mass and in other Toro rocks, for some 50 miles to the east, roughly parallel to the direction of the rift valley through Uganda. The nose of the mountain itself gradually plunges down to the north until it is hidden by a cover of Kisegi and Kaiso sediments which merge into the broad alluvial flat of the Semliki river. The rift and newer sediments are some 25 miles broad at this point, and probably mark, as stated above, the deepest part of the depression.

The series of faults which bound the Ruwenzori mass on the western side is compounded of elements which have a differing strike one from another, with the general tendency that as one goes north the individual fractures strike gradually more easterly. The faults which then bound the rift at the base of the nose probably run out under the flat ground formed by the Kisegi and Kaiso beds and the alluvium on the right bank of the Semliki. Normal faulting is to be observed near the hot springs at the base of the nose, and the fault breccia is marked by

calcification and silicification. The hade to the west varies between 10° and 30°.

The mountainside itself on the eastern side is marked by steep facets and hanging valleys as well as shelves, suggesting a rapidly sinking rift floor with at least one halt which may match with that indicated by the sediments of the Nkussi-Muzizi. Cross faults, sometimes reversed, occur across the nose, but are not marked topographically.

A well-known oil seepage occurs at Kibuku, near the base of the nose, and is clearly coincident, as is that to the north, with a major rift fault. In the hope of tapping oil in the porous Kisegi beds which lie below the cap of clays and sands of the Kaiso, a programme of deep drilling has been carried out by the writer's department, which had for its object the examination of the main rift fault. The fracture itself was cut in one deep hole where fault breccia was struck, and the fault was found to have a hade of 15° to the west.

Gravimetric measurement across the flats and submerged nose and up on to the granitoid plateau to the east has recently been carried out by Mr. D. M. Boyd, whose findings will shortly be published. Earthquake tremors are frequent along the line of the rift and are indicated on the Entebbe seismograph, but twenty-five years of records show that the movements are all very slight.

The Lake George Section.—Rolling country rising to some 5,000 feet divides the Lake Albert basin from that of Lake George and Lake Edward, and is covered in patches by a relatively thin coating of recent tuffs and agglomerates. Volcanic activity is also notable on both flanks of the more southern depression and has been described by Holmes. The Lake George Section of the rift is flanked on the west by the highly dissected slopes of Ruwenzori and on the east by generally high plateau and hill elements which fall in two steps to the floor of the rift.

The plateau elements lie broadly at between 6,000 and 7,000 feet and are composed mainly of interbedded sandstones and argillaceous beds of the Karagwe-Ankolean System. The western edge of the plateau is marked by a steep erosional scarp of irregular outline.

The middle step is composed of rolling hills of micaceous Toro rocks, whose flat tops all lie at about 4,500 feet. According to Roberts, water-worn pebbles of quartzite are found on the top of most of these hills, indicating a widespread depositional level at that height.

The middle platform is separated from the low country to the west by a fairly well defined escarpment and a marked rift fault. This has every appearance of being of a normal type, with a near vertical slope.

If compression of any degree were in evidence at the period of the rifting, it might be expected to show some effect on the Karagwe-

Ankolean beds on the plateaus, which are only 25 miles away from the outcrops on Ruwenzori. These eastern rocks, however, are amongst the most undisturbed in the system in the whole of the Protectorate, and the only folding that is in evidence is that along mainly east-west axes ; nor is there any tilt evident to the east or west in the 4,500-ft. level which was described above.

Summary of Conclusions

The writer is of the opinion that the evidence obtained over the last twelve years in Uganda is against the suggestion of compressional forces as being mainly responsible for the formation of the western rift area over its Uganda section. Rather does the evidence point consistently to tension as being, at any rate, by far the greatest contributor to the rifting.

It has been stated by Hirst and McConnell that the fracturing has taken place along the old grain of the Toro system or Basement rocks, which were subject to highly compressive forces. Records of faulting and thrusting of early age are present, but should be capable of differentiation from evidence of movement properly belonging to the rifting. Suggestions have been made by Wayland of thrusts of low angle which are masked by normal faults near the emergent trace. It is not clear to the writer how these latter could take place, but in any case pressures of the degree suggested would surely lead to considerable uplift near the edge of the rift, and thrusting as the major element might produce a considerable element of curvature in the fracture plan as a whole. The edge of the Uganda rift shows no such upturning and is compounded of a series of straight sections, which in the southern portion of the Lake Albert scarp are at a slight angle to the old metamorphic structures. The narrow, trench-like exit to the Albertine rift near the entrance of the Nile is another pointer to the probability of tension in this region.

Descriptions of the Congo side of the rift by Lepersonne indicate there also the undoubted occurrence of normal and reversed faults of steep hade parallel to the rift. Such reversed faults are to be expected if the floor is to be let down in the way suggested by the history of the rift.

Doubt of the compression hypothesis in its relationship to petrogenesis has been expressed by Bowen and Holmes.

It appears more in accord with the facts to regard Ruwenzori as a relict erosion mass, as suggested by Dixey. The high mountain range was formerly succeeded to the east by progressively lower mountain units, until the widespread peneplaned surfaces of Central Uganda are reached. This mountain group has been cut across on the east side by the rift valley, whose downward movement has been halted at least

once for a sufficient time to bring about the formation of a widespread flat erosion surface.

Both the Katanga System and later Karroo, as represented in Uganda, are cut by straight line faults of steep dip, and it is the opinion of the writer that little or no compressional force has been in evidence in Uganda since these earlier periods.

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The Age of the Malvern Folding

By W. Mykura

Abstract

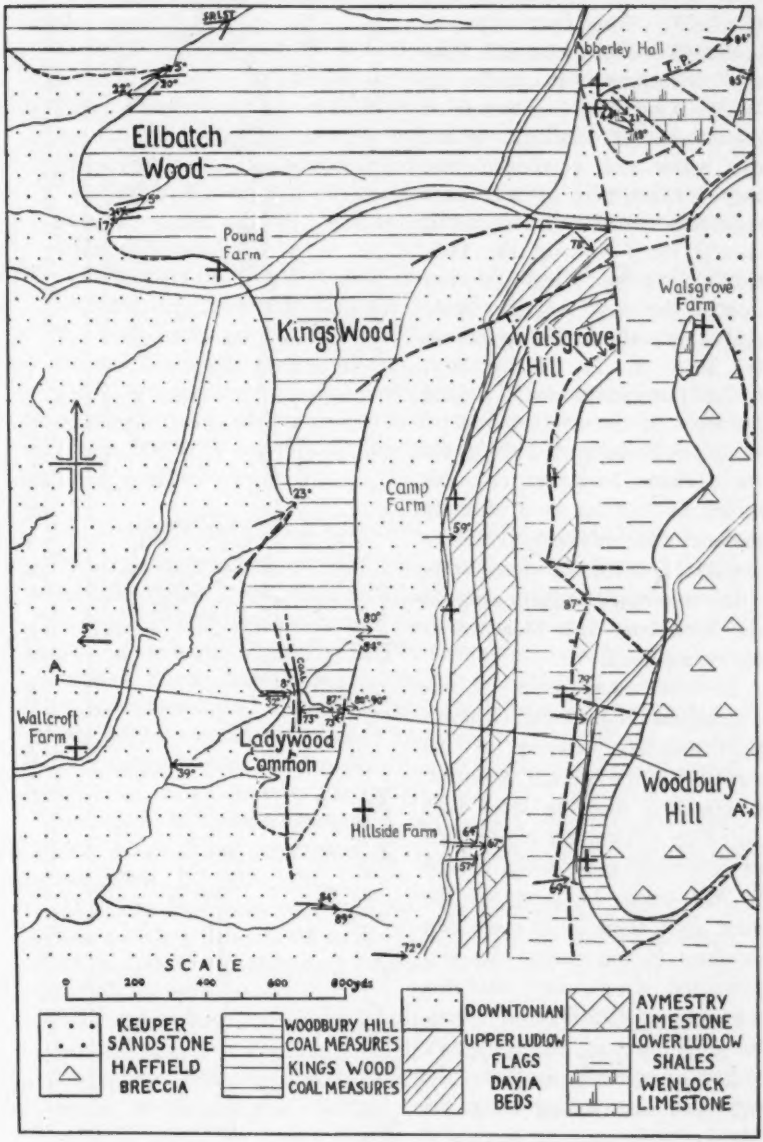
New floral and lithological evidence from the tongue of Coal Measures extending from the Wyre Forest Coalfield into the northern part of the Abberley Chain establishes that the eastward overturning along the Malvern axis is of late- or post-Morganian age. Minor folding along this axis may have taken place prior to the deposition of the Upper Coal Measures. This, however, had little topographic effect as during the deposition of the Upper Coal Measures the northern end of the Malvern axis remained an area of relatively rapid subsidence.

Introduction

THE age of the earth movements, which gave rise to the Malvern Abberley fold belt has been subject to two different interpretations. T. T. Groom (1910, p. 733) considered that the folding along this axis was part of the main Variscan orogeny and was entirely of late Upper Coal Measure age. N. L. Falcon (1947, p. 229), however, has found it difficult to reconcile the N.–S. trend of this fold belt with the E.–W. trend of the Armorican Chains and attributes the overturning to the orogenic phase which preceded the deposition of the Upper Coal Measures and is taken to represent the final phase of the Caledonian movements.

This divergence of opinion is due to the scarcity of Coal Measure outcrops in critical positions within the belt directly affected by the westward overturning. Small outcrops of apparently unfolded coal-bearing strata, including the thin wedge of Measures underlying the Haffield Breccia of Woodbury Hill, have been mapped in several areas in the Abberley Range (Groom, 1910, pp. 723–4). As these beds have yielded no recognizable fauna or flora, they give no exact guide as to the upper limit of the folding. The only outcrop of Coal Measures which is of direct value in the determination of the age of the folding is situated in the nothern part of the Abberley Chain, just west of Woodbury Hill. Here a narrow tongue of Coal Measures extends southwards from the Wyre Forest–Mamble coalfield into the area involved in the overturning.

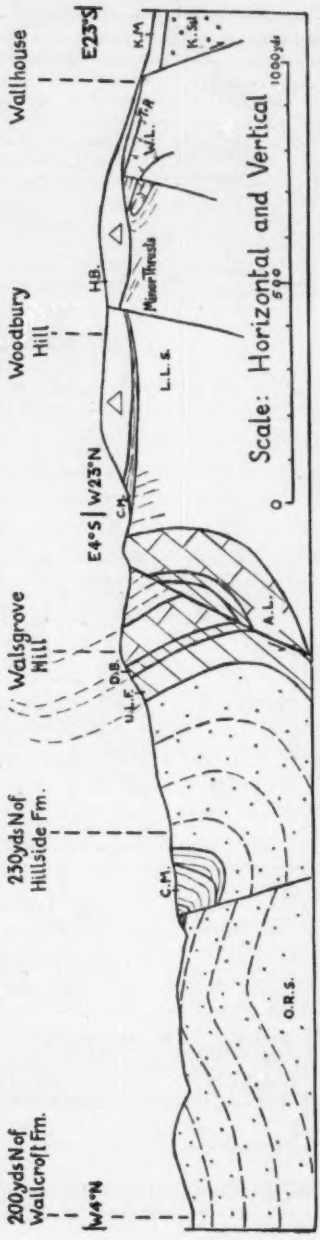
The strata forming this tongue, which will be termed the Hillside Measures, were first described by Groom (1900, pp. 173–6) who concluded from his field evidence that they were folded in conformity with the underlying Downtonian strata and formed a recumbent syncline with an inverted eastern limb. He pointed out their anomalous structural relationship to the undisturbed Coal Measures of Woodbury Hill. In a subsequent publication (1910, p. 732) Groom assumed that the Hillside Measures were stratigraphically equivalent to the Upper



TEXT-FIG. 1.—Geological sketch-map of the Northern end of the Abberley Range. A–A¹ = Line of Section.

Coal Measures of the Mamble Coalfield. The next reference to the Woodbury Hill and Hillside Measures was made by W. W. King (1923), who stressed the lithological similarity of the two series and concluded that they formed part of the same sequence. Although he noted several steep dips in the Hillside Measures, King did not uphold the view that they were folded into a recumbent syncline. In 1936 S. E. Hollingworth revised the area for the Geological Survey. In the short published summary of this work (1936, p. 45) the Hillside Measures are described as forming an apparently assymetrical syncline with a steep locally inverted eastern limb. Their anomalous relationship to the Woodbury Hill Measures is also mentioned.

In his recent paper N. L. Falcon has reinterpreted Groom's field evidence relating to the structure of the Hillside Measures. Contending that the steep dips noted by Groom are expressions of superficial contortions caused by hill creep, he expressed the view that these beds were not involved in the overturning and reiterated King's view that the measures of Hillside and Woodbury Hill are of the same age. Falcon's conclusion that the westward overturning along the Malvern axis occurred just prior to the deposition of the Upper Coal Measures is further based on the evidence provided by the non-



TEXT-FIG. 2.—Section across the Abberley Hills, showing the structural relationships of the Hillside and Woodbury Hill Measures to the older beds. T.P. = Thrust Plane.

sequences and structural trends in the areas west and south of the Malvern axis.

In the course of field work carried out in this part of the Abberley Chain, the author has measured two well exposed sections in streams cutting the eastern outcrop of the Hillside Measures (Text-figs. 1 and 2). From a consideration of these sections in conjunction with the exposures in Ellbatch Wood it can be shown that :—

(i) The main period of folding in the Abberley Hills is of late- or post-Morganian age and can be attributed to the Asturic phase of the Variscan Orogeny ;

(ii) folding on a minor scale may have taken place along the Malvern Axis before the deposition of the Upper Coal Measures. The evidence for attributing this folding to Trueman's " Malvernian " Phase is somewhat inconclusive.

The structure of the area north of Woodbury Hill suggests that a third compressive phase, characterized by low angle thrusting, succeeded the main period of overturning after an interval during which several normal faults were initiated.

Evidence for Late Upper Coal Measure Overturning

The Hillside Measures consist of thin basal conglomerates and grits overlain by buff-coloured clays and siltstones. The latter contain several thin coals, one of which attains a thickness of 2 ft. 7 in. The total estimated thickness is 350 feet. Both Groom and the officers of the Geological Survey have taken these beds to be equivalent to the Upper Coal Measures of the Mamble coalfield, which form the lowest portion of the Highley or Sulphur Coal Group of the Wyre Forest. These have been held to be stratigraphically equivalent to either the lowest portion of the Halesowen Group (Cantrill, 1917, p. 1019) or the Etruria Marl of South Staffordshire. This would suggest that the beds belong either to the upper part of the *phillipsi* or lower part of the *tenuis* zone.

As it has since been suggested that the beds forming the Hillside syncline may in fact belong to the Middle Coal Measures (Trueman, 1947, p. lxxxix), the following evidence is brought forward to verify Groom's assumption :—

(i) *Neuropteris scheuchzeri* (Hoffman), *Neuropteris* c.f. *fimbriata*, and *Lepidostrobus lanceolatus* (Lindley and Hutton), a floral assemblage described by Kidston (1917, p. 1019) as typical of the Staffordian Series of the Mamble coalfield has been obtained from a buff siltstone occurring 4 feet above the highest conglomerate in the stream 300 yards N.N.W. of Hillside Farm.

(ii) The clays underlying the plant-bearing horizon are characterized by the presence of numerous subrounded fragments of

vitrinite, which attain a maximum diameter of four inches. In the stream 460 yards west of Camp Farm the fragments occur at the same horizon above the conglomerate. From here the outcrop of this bed can be traced to a similar horizon above the highest conglomerate in Ellbatch Wood. The Coal Measures of Ellbatch Wood, which are thus stratigraphically equivalent to the Hillside Measures, can in turn be correlated with those occurring in the better known portion of the Mamble Coalfield. In the more northerly stream section in the wood a pale red clay crops out at a horizon which lies about 80 to 100 feet above the basal beds. It corresponds to the " Horseflesh Clay " recorded from a similar horizon in Yew Tree Pit, Clows Top, Mamble. (Whitehead and Pocock, pl. iv). A *Spirorbis* Limestone occurring about 10 feet above the " Horseflesh Clay " in Yew Tree Pit is represented in Ellbatch Wood by a dark grey argillaceous limestone which is characterized by the abundance of *Carbonita rankiniana* and the presence of *Carbonita* c.f. *secans* together with placoid scales.

The deeply entrenched stream 300 yards N.N.W. of Hillside Farm gives an almost unbroken exposure of strata extending for some distance above and below the plane of unconformity. It shows numerous highly inclined dips both in the Downtonian strata, the inverted condition of which has not been disputed, and in the Coal Measures. The close agreement both in direction and amount of the dips in this section with those in the stream section 210 yards to the north further suggests that they are of true structural significance and not due to hill creep. Finally, the coal seam re-excavated in an old pit in Ladywood Common shows a dip of 73° to E. 10° S. which is said by the farmer to remain approximately constant to a depth of seven yards.

Further evidence for a post-Morganian phase of folding of Malvernian trend has been recorded in the Forest of Dean Coalfield by Trotter (1942, fig. 9), where the Morganian strata forming the Staple Edge monocline and Ridge anticline show evidence of marked compression along a generally N.–S. trend.

Evidence for Early Morganian Folding

The study of lithological variations, non-sequences, and angular unconformities in the Bristol–Somerset, South Wales, Wyre Forest, and Coalbrookdale Coalfields (Trueman, 1947, p. xcix) indicates that the earth movements following a Malvernoid trend, which are attributed to the Asturic phase, had little or no effect in the areas west of the Malvern Axis. The pre-Namurian and early Morganian Movements had a more widespread effect, but the evidence for contemporary phases of active folding along the Malvern Axis is inconclusive.

Moore and Trueman (1939, p. 64) tentatively postulated a

" Malvernian Phase " of folding along the southward extension of the Malvern Axis in the Bristol Coalfield.

The lateral variations in lithology and the presence of an unconformity in the Hillside Measures, as described below, also provide some evidence for a pre- or early-Morganian phase of folding of Malvernoid trend. The basal beds of these measures consist of several thin conglomerates and grits interbedded with calcareous sandstones and siltstones. In Ellbatch Wood, where the Coal Measures rest on Downtonian beds with an angular unconformity of 30°, the basal beds reach a maximum thickness of ten feet. They thin out rapidly to the north, and are completely absent in the Pensax area. South of Ellbatch Wood the coarse-grained basal beds also diminish in thickness, but instead of a single composite band of conglomerates, grits, and sandstones, there occur two distinct conglomerates separated by a variable thickness of red and purple variegated mudstones and siltstones, lithologically indistinguishable from the underlying Downtonian strata. The basal conglomerate, which is conformably overlain by red beds, bears a fairly conformable relationship to the Downtonian. The upper conglomeratic band, which forms the basal member of the productive measures, oversteps the red measures both west and east of the synclinal axis, the amount of angular unconformity being as shown in Text-fig. 2. This suggests that the beds underlying the upper conglomerate formed a shallow asymmetric N.–S. trending syncline at the time of its deposition. The underlying red beds, preserved only in the axis of the syncline, were completely removed by the intervening period of erosion in the Ellbatch Wood sections.

There is no faunal evidence regarding the age of the lower conglomerates and red beds. They are not considered to be part of the Downtonian succession as no similar conglomeratic beds are present at an equivalent horizon in the stream 300 yards S.S.W. of Hillside Farm and no lenticular conglomerates have been recorded in Downtonian beds near the Abberley Hills. Beds of Etruria Marl facies are uncommon in the basal measures of the Highley Group of the Wyre Forest, but form 300 feet at the base and 200–300 feet at the top of the Middle Coal Measures (Kinlet Group) of that coalfield (Whitehead and Pocock, 1947, pp. 40–8). It is thus possible that the Middle Coal Measures, which are overlapped by the Highley Group south of the central basin of the Wyre Forest Coalfield reappear in the axis of this pre-Highley Group syncline.

Differential Movements in Middle and Upper Coal Measure Times

The occurrence of Middle Coal Measures in the Abberley district would further suggest that, whereas at that time the land to the south and east of the Wyre Forest was slowly rising and formed part of the

Midland Barrier, the Malvern axis formed an area of relative subsidence. After the early Morganian folding, which did not lead to the formation of a belt of high relief, this part of the Malvern axis appears again to have become a belt of relative subsidence. The splitting and deterioration of the coal seams of the Mamble Coalfield when traced towards the Abberley Hills is described by Arber (1914, pp. 379–380). The Hillside Measures are much thicker than the equivalent beds of the Mamble area and the lowest seam is represented only by a layer of coal fragments. The highest portion of the Hillside Measures, in which the 2 ft. 7 in. coal is developed, indicates a normal coal swamp rate of subsidence. This suggests that the northern end of the Malvern axis ceased to be a negative belt shortly before the deposition of the *Spirorbis* Limestone.

The Asturic earth movement along the Malvern axis is a major factor contributing to the change in environmental conditions in Central England from almost normal coal-swamp conditions inherent during the deposition of the Coalbrookdale–Highley–Newcastle Groups to the semi-desert conditions under which the Keele Beds were deposited. For this no other satisfactory explanation has been given (Wills, 1948, pp. 56–7).

The author is indebted to Professor L. J. Wills who has read the proofs of this paper and has offered many valuable suggestions.

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The Glen Dessarry Marble and its Associated Calc-Silicate Rocks.

By W. T. Harry

Abstract

White marble in Glen Dessarry, West Highlands of Scotland, occurs as three lenses associated with schists and calc-silicate rocks. The minerals identified in all these rocks are apatite, biotite, calcite, chondrodite, clinochlore, clinozoisite, diopsidic-pyroxene, dolomite, epidote, forsterite, garnet, hornblende, magnetite, phlogopite, plagioclase, potash-feldspar, pyrites, quartz, scapolite, sillimanite, sphene, vesuvianite, zoisite.

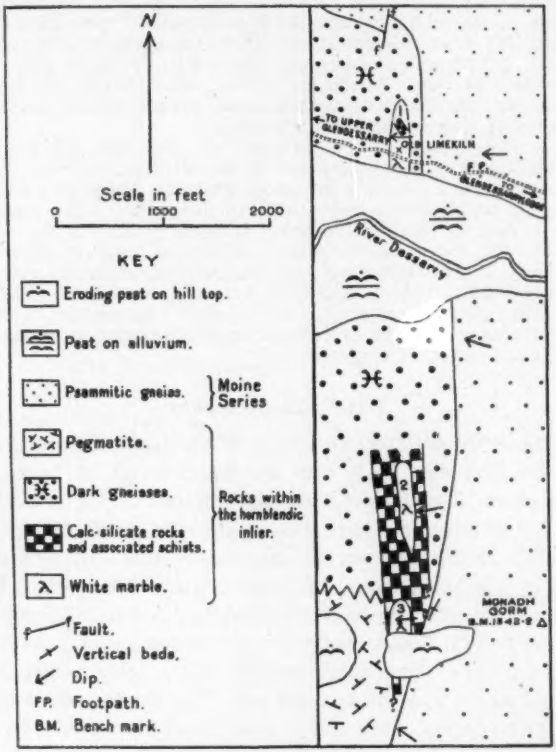
Two parageneses may be distinguished. One, due to high-grade regional metamorphism, apparently with little or no introduction of material, is a diopsidic-pyroxene, forsterite, phlogopite, calcite, dolomite association forming white marble. The other association occurs as veinlets and small irregular bodies in the white marble. It appears to be due to circulating solutions in which pyroxene and forsterite were unstable. Minerals of this paragenesis include potash-feldspar, plagioclase, scapolite, hornblende, minerals of the epidote group, calcite, and quartz. In certain localities scapolite formed at the expense of plagioclase and was succeeded by crystallization of epidote.

Field Relationships

LYING in the country north-west of the Great Glen of Scotland, Glen Dessarry leads into the western end of Loch Arkaig, Inverness-shire. The district is largely occupied by Moine schists and gneisses. A sharp anticline in these rocks runs across Glen Dessarry in a roughly NNE direction. In the core of this fold is exposed a small inlier chiefly composed of gneiss containing oligoclase, potash-feldspar, hornblende, pyroxene, and biotite. A basic to intermediate gneiss, here termed " dark gneiss ", is a common variety. Within dark gneiss and close to the eastern margin of the inlier a belt of white marble and calc-silicate rocks crops out. The marble, which supports a bright green grassy cover, forms three lenses numbered 1 to 3 from north to south on Text-fig. 1. These and their associated calc-silicate rocks are referred to below by those numbers.

Marble 1 was noted about 12 years ago by Mr. V. A. Eyles in an unpublished report to H.M. Geological Survey. It may be examined at the old limekiln mid-way between Glendessarry Lodge and Upper Glendessarry. A small stream running roughly north to south crosses the path at that place, and on its western banks white marble forms a low bluff weathering with a fluted appearance. About 50 feet of marble is visible. Roughly 100 yards from here, up the small stream and near a wire fence, the relationships between marble and green coloured calc-silicate rocks are seen. Here, on the western side of the stream, the contact between these two rocks is sharp and concordant,

the latter dipping westwards under the marble. Lineation in the green rocks, due to parallel orientation of dark minerals and of elongate lenses of different mineral composition, pitches westwards also at about the same angle. Downstream from here towards the limekiln the stream bed exposes green calc-silicate rocks before crossing into the



TEXT-FIG. 1.—Geological map showing the Glen Dessarry Marble and its associated calc-silicate rocks.

main white marble which becomes blue-coloured near the contact. The green calc-silicate rocks of this stream section contain areas of white marble several feet wide terminating northwards within a few yards. One of these areas includes a patch of blue marble and cuts sharply across the lineation of the green rocks with which it is in contact. The latter by accession of alkali feldspar, disappearance of certain minerals, and increase in grain-size, appear to pass downstream into dark gneisses near the footpath below the limekiln. It has not been

possible to show on Text-fig. 1 all these small patches of silicate rock in Marble 1.

Marble 2 crops out in the northern slopes of Monadh Gorm. On its western margin dark gneisses bear thin lenses of green diopsidic rock dipping west at 80° parallel to the lineation of the enclosing dark gneiss. The eastern margin of the marble roughly follows the strike of a belt of schist and impure calcareous meta-sediments about 30 yards wide and dipping steeply westwards. This belt is succeeded to the east by dark gneiss. The latter sends slightly transgressive lobate protrusions into the meta-sediments along their bedding.

Marble 3 forms a broad outcrop near the summit of Monadh Gorm, containing numerous steeply pitching calc-silicate lenses. It runs up to the surrounding Moine rocks, which show a discrepancy in strike with the marble, but the actual contact between the two rocks is not seen.

Petrology and Mineralogy

All refractive index determinations given are subject to error $\pm$ ·002 and have been determined by the immersion method. 2 V measurements were made on the Universal Stage in sodium light. A full list of minerals identified in the marbles and calc-silicate rocks is as follows :—andesine, apatite, biotite, calcite, chondrodite, clinochlore, clinozoisite, diopsidic-pyroxene, dolomite, epidote, forsterite, garnet, green hornblende, magnetite, oligoclase, phlogopite, potash-feldspar, pyrites, quartz, scapolite, sphene, vesuvianite, zoisite.

Marble 1 is a white marble chiefly composed of undeformed calcite crystals up to several mm. wide, with some dolomite. Rounded grains of forsterite occur, both fresh and serpentinized. Serpentinization is commonly not accompanied by liberation of iron ore. Forsterite is often concentrated in small, usually serpentinized patches, which, on fresh fracture, appear grey within the white marble. Diopsidic-pyroxene, colourless or pale green in thin section, and phlogopite, also occur either scattered throughout the marble or concentrated in patches. These patches may be sometimes accompanied by quartz, sphene, magnetite, epidote minerals (often intergrown intricately with calcite), apatite, or scapolite. The last, with birefringence indicating mizzonite, may enclose either pyroxene, sphene, or clinozoisite. A chemical analysis of the white marble is given in Table 1. The chemical composition is similar to that of a composite sample of 345 sedimentary limestones (containing some clay and sand) quoted by Clarke (1924) and listed in Table 1.

Small areas of blue marble in marble 1 chiefly consist of undeformed calcite grains up to ·5 cm. or so across and comparatively free from microscopic inclusions. A powdery yellow mineral in blue marble was identified by an X-ray powder photograph as vesuvianite. Vesu-

vianite was also identified in thin section. Scattered phlogopite, magnetite, garnet, and diopsidic-pyroxene crystals also occur in the blue marble.

Ice-blue marble has been described by von Eckermann (1922) who suggested the colour to be due to small scales of mica reflecting the light. This explanation would not seem to account for the Glen Dessarry blue marble however.

In experiments kindly performed by Mr. E. M. Patterson the blue marble was non-fluorescent in ultra-violet light. A few grains dried in a crucible for 4 hours at 110° C. showed no change in appearance. The sample was then heated in an electric muffle furnace at 350° C.

TABLE 1.

	Marble 1. [1]	*Composite analysis of 345 Limestones.* [2]	*Phlogopite from Marble 3.*	*Clinochlore from Marble 3.*
SiO_2	2·66	5·19	37·98	30·29
Al_2O_3	·32	·81	18·15	17·66
FeO	·27	·54	5·58	1·08
Fe_2O_3	·06		·23	·51
TiO_2	Nil	·06	·87	·32
MnO	Nil	·05	Nil	Nil
CaO	52·42	42·61	Nil	·43
MgO	4·38	7·90	23·52	35·12
K_2O	·19	·33	8·69	—
Na_2O	Traces	·05	1·64	—
H_2O-	·17	·21	·48	·78
H_2O+	·96	·56	3·12	13·92
CO_2	38·18	41·58	—	Nil
P_2O_5	·07	·04	Traces	Traces
	99·68		100·26	100·11
			S.G. = 2·81	S.G. = 2·64
			2V(−) almost zero.	2V(+) variable up to 30°.
			$\beta = 1·598$.	$\beta = 1·574$.

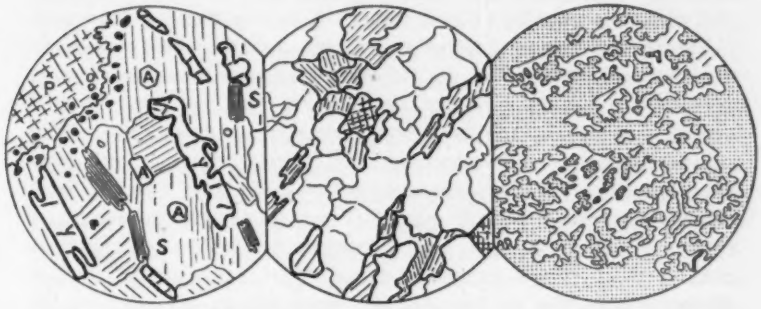
Analyses by Herdsman, except composite sample.

(thermocouple measurement) for 18 hours with free access of air. On cooling the blue colour was no longer present but the specimen was still non-fluorescent in ultra-violet light. Loss of weight on heating was about 0·03% and might be explained merely by loss of water rather than by loss of the " blue colouration ". Ca, Na, Li, Ba, Sr, Mg were detected during visual spectroscopy of a pure carbonate sample from which the silicate minerals had been separated.

[1] Cf. also the following analysis of Glen Dessarry marble by C. O. Harvey, 1948, *Mem. Geol. Surv., Min. Resources*, xxxv ; $CaCO_3$ 92·62, $MgCO_3$ 4·60, SiO_2 2·0, Al_2O_3 1·0.

[2] Quoted by Clarke, F. W. The Data of Geochemistry, *USGS. Bull.*, 770, 1924.

Whilst no conclusions are here offered about the nature of the blue colouration in this calcite it is interesting that Shazli (1950) has recently spectrographed 16 hydrothermal calcite specimens from lead-zinc veins. Most of the specimens were colourless or white, two were pale purple, two faint rosy coloured, and one faint yellowish. The spectrographic technique employed was a modification of Mitchell's cathode layer arc method, using a Hilger wide dispersion quartz spectrograph.



TEXT-FIG. 2.—All X50, ordinary light.

A. Green calc-silicate rock, Marble 1. Green clinopyroxene (P) with numerous small sphene grains around its borders. Apatite (A), biotite (closely ruled), epidote (heavy outline), large (ruled and S) plates of scapolite apparently replacing the pyroxene with liberation of sphene.

B. Diopsidic-pyroxene and quartz, lens in Marble 3. Source of material for chemical analysis of pyroxene (see text).

C. Pyroxene-zoisite intergrowth from a zoisite veinlet in Marble 3. Zoisite, forming a single crystal, is stippled. It has 2 V almost zero and is accompanied by abundant small sphene grains not shown on the drawing and possible due to liberation of titanium during replacement of pyroxene by zoisite. The pyroxene is a faint green monoclinic variety forming relict crystals up to several mm. long in process of replacement by zoisite (see text).

Although Mg, Na, Sr, Ba, Ti, V, Cr, Mn, Fe, Ni, Cu, Al, Ag, Si, Pb were detected in various specimens there appeared to be no significant difference in the trace element assemblage of white and colourless calcites on the one hand and coloured calcites on the other. Rosenholtz and Smith (1950) attribute the colour of blue Crestmore marble to residual strain, relieved by heating the specimen, and not to chemical impurities.

The green rocks associated with Marble 1 are sheared ; minerals of like grain-size and species are partially concentrated in thin parallel lenses. Bent micas and granulation are frequent. A pale green clinopyroxene occurs associated with epidote and scapolite (Text-fig. 2A). The scapolite, birefringence about 0·030 indicating mizzonite, is often

altered to an isotropic substance with refringence greater than that of Canada Balsam. This isotropic material frequently forms rounded areas enclosed by epidote which appears to be replacing it. Brown biotite, accessory sphene, apatite, and interstitial carbonate are common.

The mineral association just described, together with potash feldspar and oligoclase, forms pale coloured lenses in the green rocks. Dark lenses in the green rocks are essentially the same, but without feldspar and with deep green hornblende instead of, or in addition to, pyroxene.

Marble 2. This is a fairly pure white carbonate rock apparently identical with Marble 1. On its western margins there occur rocks composed of diopsidic-pyroxene, epidote, and clinozoisite with accessory sphene. A light brown coloured garnet occurs locally. Other calc-silicate rock varieties include a diopside-quartz rock, and types bearing a deep green hornblende with $\beta = 1{\cdot}650$, Z $\wedge$ c = 15°, X = yellowish-brown, Z = dark green. One specimen shows clusters of pyroxene crystals set in a base of colourless minerals. Along their margins the pyroxene aggregates break down into scattered crystals diminishing in size as they become more highly dispersed in the colourless base. The latter is andesine, altered to small scapolite aggregates ; scapolite also forms large fresh plates, birefringence about 0·030. Epidote in well-shaped fresh crystals is enclosed by highly scapolitized andesine.

Marble 3, closely comparable with Marble 2, is chiefly calcite often dusty with fine inclusions and showing twin lamellae bisecting the acute angle between the cleavage planes. Some faintly brown coloured dolomite crystals occur, with S.G. 2·86, $\omega = 1{\cdot}678$, and undissolved by cold dilute HCL acting for several hours. Disseminated phlogopite and forsterite ($n\gamma = 1{\cdot}670$) may be present, the latter being often only slightly serpentinized. Steeply pitching lenses of diopsidic rock are frequent. Quartz, sphene, or interstitial calcite may be present in the lenses. Partial chemical analysis of a diopsidic-pyroxene from a quartz-pyroxene rock (Text-fig. 2B) gave SiO_2 — 51·50 ; Al_2O_3 — 0·64 ; FeO — 4·26 ; Fe_2O_3 — 0·97 ; CaO — 23·78 ; MgO — 16·31 (Anal. Herdsman). Some physical constants are :—S.G. 3·28, 2 V (+) 58°, α 1·682, γ 1·712, colour of grains green. For comparison with this analysis the following theoretical weight per cent values for diopside are quoted :—SiO_2 55·48 ; CaO 25·90 ; MgO 18·62.

Scapolite, $\omega = 1{\cdot}582$, $\epsilon = 1{\cdot}550$ indicating mizzonite may occur in Marble 3. Phlogopite forms small clusters of brown plates up to 1 cm. across, a hand-picked sample of which was chemically analysed (Table 1). Hallimond (1926) has plotted biotite and phlogopite analyses using molecular ratios RO and R_2O_3 for (Si, Ti)O_2 = 600. Calculated to this basis the Glen Dessarry phlogopite RO 620 R_2O_3 166

falls within, and close to the boundary of, the phlogopite-biotite field, near the phlogopite end of Hallimond's (1926, p. 29) diagram.

Clinochlore forms small aggregates as does phlogopite but whereas in aggregates the plates of the latter tend to parallel orientation, the clinochlore tablets do not, suggesting them to be later than the phlogopite. Perhaps they grew at the expense of phlogopite under physical conditions different from those that obtained during crystallization of phlogopite. A chemical analysis of a hand-picked clinochlore sample is quoted in Table 1.

Chondrodite occurs in two thin sections. One of these sections is chiefly forsterite with interstitial calcite, some of which is turbid with inclusions and may possibly be late calcite generated by de-dolomitization. The chondrodite forms small irregular areas sometimes associated with minute granules of opaque material. It may occur either enclosed by calcite or as grains projecting into phlogopite, as thin films on the edge of phlogopite flakes, or as strings of small grains marginal to forsterite. This last mode of occurrence is similar to that of the Glenelg chondrodite described by Read and Double (1935) considered by them to indicate formation of chondrodite from forsterite by fluorine- and hydroxyl-bearing solutions.

The Glen Dessarry chondrodite is pleochroic, X = yellow, Z = almost colourless. The maximum interference colour observed was red 2nd order. One crystal of good form gave an extinction angle of 32° on the cleavage. Some individuals show polysynthetic twinning; if the twin plane be taken as (001), the common twin plane in monoclinic humites, then the extinction measured on this plane is 19° at least. Measurements of 2 V in sodium light on the Universal Stage gave 2 V (+) 71°.

Finally, of general relevance to the metamorphic history of the marble is the occurrence, immediately adjacent to its eastern margin and near the top of Monadh Gorm, of brown weathering schist rich in sillimanite.

Veinlets

Thin zoisite veinlets cut diopsidic rocks in Marble 3. The zoisite is intergrown with calcite and has a very low 2 V. In one case it forms an intergrowth with the diopsidic-pyroxene of the enclosing rock apparently by replacement of the latter (Text-fig. 2C). Clinozoisite and scapolite may occur together in some veinlets.

At all three marble localities, particularly in the silicate rocks, there occur veinlets of potash feldspar and oligoclase with some biotite, green hornblende, clinopyroxene relict in amphibole, and accessory sphene. Scapolite with birefringence indicating mizzonite may occur sometimes as thin strings cutting across feldspars and tending to alter

to an isotropic substance with R.I. greater than that of Canada Balsam. Scapolite may also send intrusive wedges in between feldspar crystals and may poikiloblastically enclose feldspar.

Secondary calcite veins up to 1 ft. wide cut the marbles, and some quartz veinlets with striated pyrite cubes have been seen. Besides veinlets the silicate minerals of the veins sometimes form small isolated aggregates in the white marble. These have been remarked upon in the description of the marble.

General Conclusions on Metamorphism

The general mineral assemblage of the Glen Dessarry marble is similar to that of the South Harris marbles described by Davidson (1943) in which calcite, dolomite, and forsterite are always present and diopside and phlogopite are common. Davidson believes that the South Harris marbles have been regionally metamorphosed and compares them with several regionally metamorphosed marbles from other countries.

The total mineral assemblage of the Glen Dessarry marble and calc-silicate rocks constitutes two parageneses. One of these is a diopsidic-pyroxene, phlogopite, forsterite, dolomite, calcite association forming white marble. The presence of dolomite shows that this metamorphism did not attain Bowen's (1940) fifth reaction and that the normal limits of regional metamorphism were not exceeded. On the other hand abundant diopsidic-pyroxene shows that Bowen's third reaction took place. This paragenesis in the geological environment described is accordingly indicative of high grade regional metamorphism. Bowen's reactions 3–5 fall within Eskola's amphibolite mineral facies (Turner, 1948). There is therefore general equivalence between the metamorphic state of the marble and that of the associated feldspar-hornblende gneisses (" dark gneisses ") which may be assigned to the same facies from the association of lime-bearing plagioclase with hornblende. Sillimanite-schist adjacent to marble 3 further indicates amphibolite facies conditions within the inlier. Therefore it seems that during metamorphism the marble was not soaked by solutions capable of eliminating CO_2 from the system. Such solutions would have radically altered the course of crystallization in the marble compared with rocks devoid of carbonates, because in contrast with the latter carbonate rocks are extremely sensitive to changes in the effective pressure of CO_2 during metamorphism. A marked difference in metamorphic grade between the carbonate and non-carbonate-bearing rocks would have resulted.

Chemical evidence indicates that metamorphism of the Glen Dessarry white marble took place with little, if any, introduction of material. There is a close similarity between the chemical composition of the

marble and that of a composite sample of 345 sedimentary limestones (Table 1) quoted by Clarke (1924). The marble therefore does not seem to have been intimately soaked by introduced solutions radically altering its chemical composition during metamorphism, although solutions were available.

The Glen Dessarry marble must have been very resistant to percolating solutions ; the gneisses of the inlier have been highly migmatized by introduced feldspathic material and they are accompanied by abundant pegmatite. Alkali-silicate solutions surrounded the marble but on the whole they only entered the latter along definite paths to form scattered thin veinlets, leaving the main body of marble unaffected.

These remarks agree with Bowen's (1940) contention that ordinarily during metamorphism carbonate rocks are not subject to freely circulating solutions or at least that if such solutions are present they are not capable of removing significant quantities of CO_2 from the system. His point is fundamental to the validity of metamorphic zonal work on carbonate-bearing rocks. Generally speaking it practically eliminates a potentially important variable and with due care permits some comparison between regional metamorphic studies of carbonate- and non-carbonate-bearing assemblages.

The white marble just discussed is cut by veinlets in which different equilibria prevailed during crystallization. The veins may be ascribed to introduced solutions carrying alkali-silicates and probably deriving much of their other constituents from the adjacent calcareous rocks. The vein-forming solutions also appear to have permeated certain calc-silicate rocks associated with the marbles, developing green hornblende from pyroxene and forming feldspar and perhaps scapolite and epidote. In some places they penetrated the marble to form small isolated centres of crystallization of minerals that elsewhere form veins in the marble.

Forsterite and dolomite have not been noted in the veinlets and pyroxene only rarely occurs, then being seen in process of replacement. These three minerals therefore seem to have been unstable under vein conditions. In the metamorphic limestones of Adelie Land Tilley (1923), it is interesting to note, has shown that microcline, plagioclase, scapolite, and epidote enter only after the disappearance of pure magnesium silicates, dolomite, and spinel.

Movement of Marble

The marble occurs as three thick lenses associated with undoubted meta-sediments and therefore is most probably of sedimentary origin itself. The lenticular form is not likely to be an original deposition feature. It may be due to deformation by earth movements of one

originally continuous sheet. This idea has been used by Davidson (1943) to explain the lenticular form of marble bodies in Harris. There are good experimental and geological reasons to support this hypothesis. Marble is readily deformed under laboratory conditions whilst in regional metamorphic areas its capacity to flow under earth movement is well known.

The Glen Dessarry marble also bears direct evidence of movement. It contains angular calc-silicate-rock fragments which are seen to have originally formed sheets now broken up and their pieces pulled apart. In the stream section in marble 1, close to the limekiln, a patch of marble is enclosed by green calc-silicate rocks. This marble lies in sharp contact with latter and abruptly cuts across a marked lineation in the green rocks as if it had been intruded into them. Weathered exposures of white marble in the bluff by the limekiln show subparallel minute discontinuous ridges about a mm. high and following the general strike of the marble. They flow around small calc-silicate-rock inclusions in the marble. Apparently they are due to concentration of silicate minerals along thin layers in the white marble. Similar concentrations described by Bruce and Russell (1939) are ascribed by those authors to shearing along bedding planes.

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Some Unusual Structures in Rhaetic Sandstones, near Cowbridge, Glamorgan

By Trevor M. Thomas

Abstract

The best known exposures of Rhaetic strata in Glamorgan are those of the Lavernock and Penarth cliff sections, where the normal black shales—thin limestones facies are displayed. In the central and west Vale of Glamorgan, however, massive sandstones are the dominant Rhaetic formation. The construction of a housing site has revealed the presence of numerous voids or cavities in these sandstones, the origin of which is attributed to decalcification.

Introduction

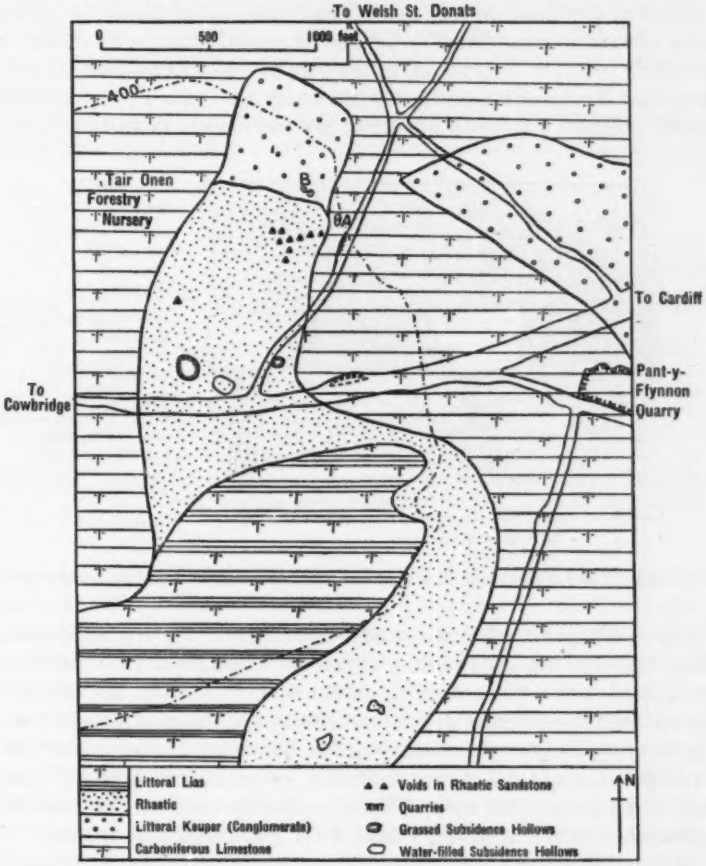
THE Rhaetic Series of South Wales forms a very thin "passage" group between the Keuper and Lower Lias. The beds rarely exceed 40 feet in total thickness, but are remarkably persistent and, except where faulted contacts occur, form a narrow outcrop separating the broad tracts of Lower Lias country in the Vale of Glamorgan from the detached outcrops of Littoral Trias immediately to the north.

When traced westwards along the central portions of the Vale of Glamorgan the normal Rhaetic shales are in part replaced by a more arenaceous facies between Bonvilston and Cowbridge. An intermediate stage in this change of lithology is the oncoming of calcareous marls and sandstones or oolitic limestones containing so much sand as to weather or decalcify into rotten sandstones. Massive Rhaetic sandstones thus occur at Tair Onen, two to three miles east of Cowbridge.

General Description of the Tair Onen Area

This area occupies part of the higher or 350 to 400 feet platform of the Vale of Glamorgan and shows no distinct relief feature. Light grey oolites and standard blue-grey shelly limestones of the Carboniferous Limestone Series underlie the whole area. These dip southward at angles of 10 to 15 degrees. Overlapping, approximately horizontal cappings of Littoral Trias, Rhaetic and Littoral Lower Lias reduce considerably the extent of outcrop of the limestone group. Thus in the eastern half of the Tair-Onen Forest Nursery a wedge shaped outcrop of Rhaetic sandstones overlaps the Carboniferous Limestone as does a small outlier of Littoral Trias. South and south-west of this sector the Rhaetic is itself overlapped by a more extensive mass of Littoral Lias.

A short distance to the east of Tair Onen and immediately adjacent to the main Cardiff to Cowbridge road the active quarry of Pant-y-ffynnon works beds of the Carboniferous Limestone Series and has encroached upon an overlying mass of Littoral Trias. The Rhaetic

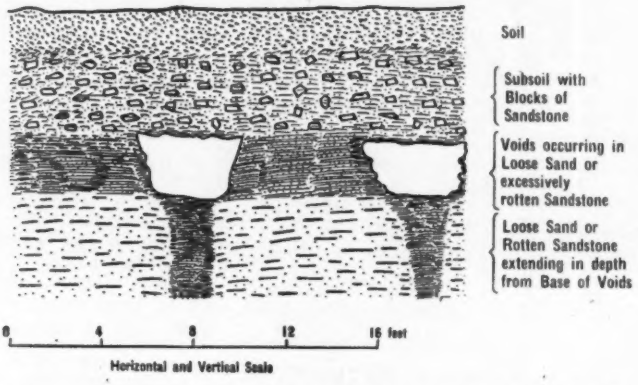


TEXT-FIG. 1.—Map of the Tair Onen area, Cowbridge, showing location of voids and subsidence features in Rhaetic Sandstones.

outcrop is untouched by quarrying operations, past or present. Recent excavations for a new housing site have, on the other hand, been of great value in elucidating the lithology of the Rhaetic and the presence within the latter sandstones of hitherto unsuspected structures in the form of voids or cavities of limited cross-section.

Details of Voids or Cavities in Rhaetic Sandstones

During the course of construction of a network of deep drainage trenches some 10 voids were encountered. Most of these were of rough circular outline with a diameter of 3 to 4 feet and a similar depth. They occur 3 to 6 feet below the surface and form clean-cut features, neither passing laterally into well-defined stratification planes nor giving way upward to joint-planes or fissures. A typical vertical-section shows a rubbly soil, 1 to 2 feet thick giving way to 2 to 4 feet of subsoil with detached blocks of Rhaetic sandstone which are inclined to be crumbly under pressure, and finally a layer up to 4 feet thick of excessively rotten



Text-fig. 2.—Enlarged section through typical voids in Rhaetic Sandstone.

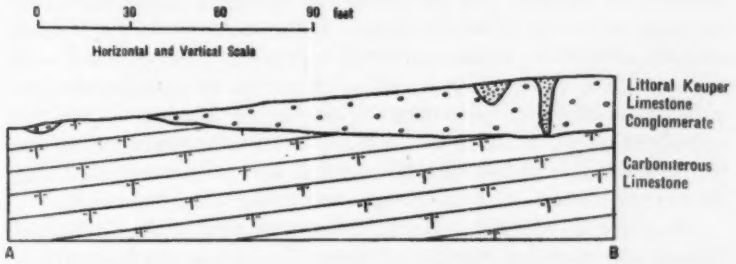
stone or comparatively loose sand. The floors of the voids are relatively flat, and the loose sand or rotten rock beneath can normally be penetrated with a hand auger to depths of 10 feet. At a few isolated points this range of penetration is increased and the overall maximum depth attained from numerous testings has been 25 feet below the surface of the ground. One exceptional void measured nearly 15 feet across and some 8 feet deep. This undoubtedly owed its origin to the coalescence of a few of the minor units into one major feature.

A distribution plan of these voids shows no distinct pattern, but they appear to be more numerous where the Rhaetic sandstones overlie a thin layer of Littoral Trias limestone-conglomerate rather than overlap directly on to the main foundation of Carboniferous Limestone.

An inspection of the Rhaetic outcrop which extends southward from Tair Onen towards the village of Llantrithyd, a mile to the south, shows five features which owe their existence to the collapse of cavities or voids within the Rhaetic itself or, alternatively, form the surface reflections of the former occurrence of such structures in the under-

lying Carboniferous Limestone. These surface hollows, three of which carry permanent water, range from 15 to 30 yards in diameter and 5 to 8 feet in depth. The adjoining Carboniferous Limestone outcrop, despite its greater extent and freedom from superficial deposits, has no comparable surface forms. Throughout a lengthy period of continual rock extraction the sections displayed at Pant-y-ffynnon quarry have given no indications of the honeycombing of the limestone by caves or underground channels as would form the initial basis of surface collapse features.

It would appear that the voids or cavities within the Rhaetic sandstones have originated as a result of the production of loose sand or



TEXT-FIG. 3.—Section across the southern end of the Littoral Keuper Outcrop at Tair Onen showing outlying occurrences of Rhaetic Sandstones (dotted).

rotten rock after loss of calcareous cement. Major joint-planes within the Carboniferous Limestone or lines of weakness in the Trias conglomerates have, no doubt, influenced the distribution of these voids in providing a passage for percolating waters and a depository for small quantities of the released loose sand.

In the north-eastern corner of Tair Onen and immediately north of the wedge-shaped outcrop of Rhaetic, under review, is an outlying patch of Littoral Trias some 200 yards in width. This consists of limestone conglomerates with rounded pebbles ranging up to a foot in diameter, but averaging 3 to 4 inches. Minor outliers of Rhaetic sandstone have been preserved on this patch of Littoral Trias. These occur up to a distance of 20 yards from the edge of the parent Rhaetic outcrop. Two such minor outliers of Rhaetic have been examined. The larger, consisting of soft crumbly sandstone, is some 12 feet in diameter and 8 feet deep. The other, although of less surface extent, is of more interest in that it has been proved to extend in depth for more than 18 feet. It appears to occupy an enlarged fissure, but it is not known whether this penetrates the full thickness of the Trias conglomerates and extends into the Carboniferous Limestone beneath.

Conclusion

It is a well-known fact that on the mountainous North Crop of the South Wales Coalfield, swallow holes and subsidence hollows caused by solution of the underlying Carboniferous Limestone are most conspicuous and on a larger scale, not on the outcrop of the latter but in the strip of country immediately to the south where this formation is overlain by Millstone Grit. The arenaceous facies of the Rhaetic in the central and western Vale of Glamorgan might be likened in many ways to the Millstone Grit, so that where the former overlaps the Carboniferous Limestone a relative abundance of subsidence or solution hollows might be expected. The absence of these can be attributed to the lower altitudes, smaller rainfall and restricted underground flow of water within the limestone mass. Surface hollows on the Rhaetic outcrop as well as cavities within the sandstones themselves are thus not so much upward repercussions of cavern or solution channel collapses within the underlying Carboniferous Limestone, but are reflections of the unstable nature of the calcareous sandstones of the formation, liable as they are to complete decalcification where they overlie joint planes or lines of weakness in the older formations.

The writer is indebted to Dr. F. J. North, Keeper of the Geological Department, National Museum of Wales, for reading this short note in manuscript.

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A New Eurypterid from the Ordovician of Montgomeryshire, Wales

By LEIF STØRMER (Oslo)

ABSTRACT

A description is given of a nearly complete specimen of a new Ordovician eurypterid genus belonging to the family Stylonuridae. The classification of the Eurypterida is discussed; two superfamilies and two new families are proposed and three new names substituted for pre-occupied generic names.

INTRODUCTION

FROM the material collected by Dr. C. J. Stubblefield and Mr. Dewar from the Lower Caradoc shaly mudstones cropping out below the Breidden Dolerite in the south bank of the River Severn, 650 yards N.W. of Bausley House, Montgomeryshire, the former recognized an eurypterid specimen which he considered to show some affinity with *Drepanopterus* of the Stylonuridae (Stubblefield, 1930, p. 88; 1932, p. 55). The eurypterid is associated with graptolites indicating a low level of the *Diplograptus* (*Mesograptus*) *multidens* zone.

Dr. Stubblefield very kindly submitted to me for description the new eurypterid which, so far as I know, is the earliest representative of the group known outside North America. I am also greatly indebted to Dr. Stubblefield for putting at my disposal his photographs and camera lucida drawings of the specimen and its counterpart.

The eurypterid specimen is preserved in a fragile dark grey to slightly brownish mudstone. During transport to Norway and later while immersed in alcohol the specimen and the counterpart split up in numerous pieces which were subsequently glued together as far as possible. The specimen is flattened in the mudstone and the dark test is but slightly discernible against the matrix even when immersed in alcohol. For this reason it has not been possible to obtain photographs suitable for reproduction. Text-fig. 1, combining the structures of the holotype and counterpart, is based on numerous drawings made using a binocular microscope fitted with a Leitz drawing ocular.

Ordovician eurypterids hitherto have been known only from U.S.A. where Clarke and Ruedemann (1912) and Ruedemann (1916, 1926, 1934) in particular have described numerous species mostly preserved as scattered fragments in graptolite shales. The genera *Stylonurus*, *Dolichopterus*, *Pterygotus*, *Hughmilleria*, *Eurypterus*, *Carcinosoma*, *Mixopterus*, *Echinognathus*, and *Megalograptus* are recorded, but the generic determination is in most cases difficult since prosomal appendages are only known in a few species. Concerning the general characters of the Ordovician eurypterid faunas ranging from the Lower Ordovician

Deep Kill Shale to the Upper Ordovician Utica Shale, one might say that all species except those of *Echinognathus* and *Megalograptus* are very small, decidedly smaller than the average of those of later faunas. As earlier pointed out (Størmer, 1936, p. 34), the very large and specialized species of the two latter genera might suggest that these forms had their acme of development in early Ordovician or perhaps even before that time.

Classification

The geological appearance of the Eurypterida does not give much clue to a natural classification of the group. In building up a taxonomic system one has to rely on certain morphological features which, from general experience, seem to be useful. As elsewhere among fossil groups, the various morphological characters develop and change at different rates leaving to the paleontologist a rather intricate pattern.

The major classification of the Eurypterida is based chiefly on the development of the prosomal appendages. In addition to this the ornamentation, the outline of the prosoma, the shape, size, and position of the lateral eyes, the outline of the abdomen, the telson in particular, the metastoma and the genital appendage have a certain value.

Applying the prosomal appendages as the more important character, one notices that the eurypterids—like all other members of the Chelicerata—have the first pair of prosomal appendages developed as pincers or chelicera. In the genus *Pterygotus* the pincers are enormously developed with strong teeth on the inner margin of the chela. Since *Pterygotus* with its subgenera *Pterygotus*, *Erettopterus* and *Acutiramus* (comp. Prantl and Přibyl, 1948) differ from all other eurypterids in this respect, Kjellesvig-Waering (1951, p. 4) has with good reason restricted the family Pterygotidae Clarke and Ruedemann to the genus *Pterygotus*; the other genera previously included in the family are placed in a new family, Hughmilleridae Kjellesvig-Waering.

Concerning the structure of the five remaining pairs of prosomal appendages, it is difficult to point out with any certainty which type of leg is the more primitive. Comparing the eurypterid species known, one notices, however, that many very different forms have the first pairs of legs developed as fairly short appendages tapering gently in width towards the terminal claw, all joints except the most proximal ones provided with a few short spines. This type of appendage is found in genera of the families Stylonuridae, Pterygotidae, Hughmilleridae, Eurypteridae, and to a considerable extent also in the Carcinosomidae. From this probably primitive type of appendage might be derived both the spineless legs of the Stylonuridae and the highly spinous legs of the Carcinosomidae.

In the Stylonuridae the last pair of prosomal appendages is similar to the walking legs further forward. In all other eurypterid families, on the other hand, the last pair of prosomal appendages forms characteristic " swimming legs " in which the distal portion of the leg is modified into a flat paddle. As shown by Clarke and Ruedemann (1912) a paddle, though less conspicuous, is independently developed in the genus *Dolichopterus* otherwise distinctly related to the Stylonuridae. The independent development is indicated by the fact that different joints take part in the formation of the paddle.

The development of the last pair of prosomal legs seems to offer a natural basis for a major classification of the Eurypterida. Below two superfamilies are suggested.

I. *Superfamily Stylonuracea* nov.

Diagnosis.—Eurypterida in which the last pair of prosomal appendages is developed as walking legs or modified into swimming legs in which the paddle is formed by the 2–3 ultimate joints.

II. *Superfamily Eurypteracea* nov.

Diagnosis.—Eurypterida in which the last pair of prosomal appendages is developed as swimming legs in which the paddle is formed by the two penultimate joints.

The superfamily Stylonuracea comprises both genera in which the last pair of appendages form typical walking legs, and genera in which swimming legs are secondarily formed. The latter comprise the genera *Dolichopterus* Hall and *Strobilopterus* Ruedemann (1935). As suggested to me by Dr. Kjellesvig-Waering, the genera with expanded last walking legs might be removed from the family Stylonuridae and placed in a new family. In a joint paper (Kjellesvig-Waering and Størmer, 1952), we are suggesting the new family *Dolichopteridae*, including the genera *Dolichopterus* and *Strobilopterus*.

The other members of the Stylonuracea have, so far as we know, the last pair of appendages developed as a slender walking leg. The genera known at present are : *Stylonurus* Page, 1856, *Drepanopterus* Laurie, 1892, *Ctenopterus* Clarke and Ruedemann, 1912, *Tarsopterella* nom. nov. (*Tarsopterus* Clarke and Ruedemann, 1912, is a preoccupied name as mentioned below), and *Rhenopterus* Størmer, 1936.

In addition to the genera mentioned come a few less well-known forms. A peculiar large eurypterid was described a long time ago by Hibbert (1836) from the Lower Carboniferous of Scotland under the name *Eurypterus scouleri*. A very similar form, a separate prosoma evidently belonging to the same genus, was later described by Kutorga (1852) from the Carboniferous–Permian of Ural, U.S.S.R. Kutorga called his species *Limulus oculatus*, but Eichwald (1860) later suggested

the new generic name *Campylocephalus* for this Russian species. Since the better known Scottish species evidently belongs to the same genus it has now to be called *Campylocephalus scouleri* (Hibbert). The prosomal legs of the genus are as yet practically unknown, but since the prosoma with its peculiar ornamentation has much in common with *Tarsopterella*, the genus *Campylocephalus* might be referred to the Stylonuridae. It should be mentioned, however, that the legs of *Tarsopterella* are likewise imperfectly known. A distinctly stylonurid leg probably belonging to the genus *Tarsopterella* was described from the Lower Devonian of Germany (Størmer, 1936, pl. 8, fig. 6).

Another peculiar genus from the Carboniferous was originally described by Cope (1886, p. 1027 ; 1888, p. 914) as a reptile under the generic name *Mycterops*. Kjellesvig-Waering (1948, p. 7) has recently shown that *Mycterops* is identical with the eurypterid genus *Glaucodes* described by Pruvost (1923, p. 143 ; 1930, p. 196) from the Upper Carboniferous of Belgium. Characteristic of *Mycterops* is the huge first tergite of the abdomen, the rest of the abdomen is unknown. Only a few undeterminable fragments of the appendages are preserved in the Belgian species. From the Lower Carboniferous of Scotland, however, Woodward (1887, p. 481, pl. 13) described a species *Eurypterus scabrosus* which also has a large first tergite, but at the same time also an equally large second tergite while the rest are of normal length. The almost complete specimens have long legs of the stylonurid type. Although the ornamentation of the test is somewhat different from that of *Mycterops*, there seem to be good reasons for regardin the Scottish species as belonging to this genus or possibly representing a new genus closely related to it. *Mycterops* thus appears to belong to the Stylonuracea, but differs considerably from the other genera of the superfamily in this special development of the first tergites.

The genus *Rhenopterus* (Størmer, 1936, p. 62) also differs considerably from the rest of the Stylonuracea. Particularly characteristic of this form is the shape of the metastoma and the lack of an epistoma.

With our present knowledge of the Stylonuracea it seems natural to establish two new families and to restrict the original family Stylonuridae to comprise genera more closely related to *Stylonurus*.

A. *Family Dolichopteridae* Kjellesvig-Waering and Størmer, 1952

B. *Family Mycteropteridae* nov.

Diagnosis.—Stylonuracea of medium to fairly large size, test with numerous scales and reticulate ornamentation, prosoma subtrapezoid, first and second tergites of abdomen very strongly developed, prosomal legs of stylonurid type.

Type genus : *Mycterops* Cope 1886 (= *Glaucodes* Pruvost, 1923)

C. *Family Rhenopteridae* nov.

Diagnosis.—Stylonuracea of small size, test with scattered tubercles and knobs, prosoma subtrapezoid, prosomal doublure with median suture and no epistoma, two (or three) first pairs of walking legs with spines, two last pairs of legs long and powerful without spines, metastoma pear-shaped with slightly concave anterior margin, genital appendage of male short with two distal spines.

Type genus : *Rhenopterus* Størmer, 1936

According to verbal information from Kjellesvig-Waering his *Eurypterus* (*Stylonurus* ?) *maccarthyi* from the Lower Devonian of New York (Kjellesvig-Waering, 1934, p. 386) may belong to the same genus.

D. *Family Stylonuridae* Diener, 1924, emend.

Diagnosis.—Stylonuracea of small to very large size, test with knobs and small tubercles developing into scales, prosoma of variable outline with subcentral to more anterior, arcuate lateral eyes, abdomen slender without or with lateral epimers, telson styliform to clavate, prosomal doublure narrow with epistoma, walking legs long and powerful with or without spines, metastoma narrow, genital appendage in male probably long, in female probably short and broad.

Type genus : *Stylonurus* Page, 1856

The family Stylonuridae includes several genera, some of which are less satisfactorily defined. At present the following genera belong to the family : *Stylonurus* Page, 1856, *Drepanopterus* Laurie, 1892, *Ctenopterus* Clarke and Ruedemann, 1912, *Tarsopterella* nom. nov., and *Campylocephalus* Eichwald, 1860. While the three last genera each are very characteristic and easily separable, the two first have more features in common and are less clearly defined.

The genus *Stylonurus* was introduced by Page (1856, p. 135) with *S. powriei* Page as the type species. Page did not describe and discuss the genus, this was done by Woodward (1866–1878, p. 121) who points out as characteristic features of the genus : " the peculiar form of the carapace, the great length of the telson or terminal point (in *S. Powriei* one-third the length of the animal), and the substitution of two pairs of long, slender, oar-like jaw-feet, instead of the single pair of broad, short, natatory organs more usually met with in this group."

The genus *Drepanopterus* was introduced by Laurie (1892, p. 159), who pointed out : " Carapace broader than long, widest about two-fifths from anterior margin. Body, 1st segment wider than posterior margin of carapace ; increases in width to 3rd segment, and tapers rapidly. Limb elongated, subcylindrical terminating in a very slightly

expanded joint, concave on posterior margin." Later Laurie (1898, p. 584) added : " Last pair of appendages neither expanded, as in Eurypterus, etc., nor excessively elongated, as in Stylonurus."

Clarke and Ruedemann (1912, p. 316) discuss the relations between *Stylonurus* and *Drepanopterus* and point out that the latter has its last pair of legs smaller, reaching only to the penultimate segment of the abdomen. The preceding legs are only three-fifths the length of the last pair.

The type species of *Stylonurus*, *S. powriei* Page, according to Woodward (1866–1878, p. 122, pl. 21, fig. 1), has an angular prosoma—unfortunately the lateral eyes are not preserved—and a narrow, more or less trilobed abdomen with a very long and powerful telson. The two last walking legs are long and keeled, but slightly tapering in width towards the terminal joint. The hind leg reaches as far as to the telson. *S. logani* Woodward (l.c., pl. 24, fig. 1), also having long and powerful posterior walking legs, has strongly arcuate lateral eyes with the axis (the straight line between the distal points of the eye) more or less parallel with the median line.

The types species of *Drepanopterus*, *D. pentlandicus* Laurie (1892, p. 159, pl. 3, figs. 16, 17 ; 1898, p. 584, pl. 4, fig. 22) has a more rounded prosoma with arcuate lateral eyes the axes of which are more or less parallel with the median line, a narrow abdomen without trilobation, terminating in a powerful but hardly very long telson. The two last pairs of prosomal legs are comparatively short, apparently cylindrical, and taper but slightly in width towards the strong curved terminal claws, the hind leg reaching as far as to about the penultimate segment of the abdomen.

The American *Drepanopterus longicaudatus* Clarke and Ruedemann (1912, p. 316, pl. 25, figs. 54–6) corresponds well with the Scottish form. The shape of the body is largely the same, though the postabdomen is narrower and the telson more clavate. The lateral eyes are strongly arcuate with the axis parallel to the median line (or slightly diverging forwards). The cylindrical, but slightly tapering, legs have a few spines on the four first pair of legs, powerful curved terminal claws on the two last pairs of legs, the hind legs reaching as far as to the penultimate segment of the abdomen.

Considering the type species of *Stylonurus* and *Drepanopterus* it thus appears that the chief generic difference is found in the length and shape of the posterior prosomal appendages.

If we turn to the many other species described under the generic names of *Stylonurus* and *Drepanopterus* the identification appears to me more difficult. In the new Ordovician species described below, the posterior prosomal appendages are short as in *Drepanopterus* but keeled as in *Stylonurus*, and at the same time differ from both

in tapering distinctly in width towards the narrow distal joint. The oblique lateral eyes with the axis converging forwards, differ from the type species of *Drepanopterus* and probably also from *Stylonurus*. Among previously described species *Stylonurus pentagonalis* Størmer (1934, p. 96, pl. 9, fig. 8 ; pl. 10, figs. 3–5 ; pl. 11, fig. 8 ? and text-figs. 1, 7, 15) probably has similar posterior legs. The fourth walking leg (V) is relatively short, keeled, and tapering in width towards the terminal claw, and the same is suggested in the last leg though here the proximal part only is preserved. In the reconstruction (l.c., text-fig. 15) the distal portion of the hind legs are merely suggested after corresponding legs in typical species of *Stylonurus*. With our present knowledge it seems more probable that these legs also were relatively short and tapering in width as in the new Ordovician species. Also the Downtonian *Stylonurus pentagonalis* has oblique eyes with anteriorly strongly converging axes.

With regard to the direction of the lateral eyes in more typical species of *Stylonurus*, it might be mentioned that in two Downtonian species with stylonurid legs : *Stylonurus ruedemanni* Størmer (1934, p. 99, pl. 10, fig. 6 ; pl. 11, fig. 1 ; text-figs. 34, 35), and *S. dolichopteroides* Størmer (1934, p. 101, pl. 9, fig. 5 ; pl. 10, fig. 1 ; text-fig. 36): the axes of the eyes are but slightly converging forwards. In the Silurian *S. myops* Clarke, in which, however, the appendages are unknown, the axes of the eyes are parallel (Clarke and Ruedemann, 1912, pls. 51–3). Converging axes of the eyes are seen in the Upper Devonian *Eurypterus arnoldi* Ehlers (1935), a species which evidently belongs to the Stylonuracea, but like the preceding cannot be definitely determined as long as the appendages remain unknown. A Silurian species described by Clarke as *Pterygotus otisius* and later by Clarke and Ruedemann (1912, p. 270, pl. 46, figs. 1–8) as *Dolichopterus otisius* (Clarke), has distinctly oblique eyes like those first mentioned. Unfortunately this species also lacks well enough preserved appendages to warrant a closer determination.

Judging from species in which both prosoma and appendages are known, the strongly oblique eyes go with the shorter, keeled tapering legs. Species with long, keeled legs of more even width seem to have eyes with parallel to slightly converging axes. Species with short, smooth legs of even width also have eyes with parallel axes. These observations seem to justify the introduction of a new genus and new definitions of the genera *Stylonurus* and *Drepanopterus*.

1. Genus *Stylonurus* Page, 1856, emend.

Diagnosis.—Stylonuridae of small to medium size, test mostly smooth, prosoma semiovate to subrectangular, lateral eyes with parallel to slightly converging axes, abdomen narrow with long,

powerful styliform telson, three first pairs of walking legs of more ordinary eurypterid type with few spines, two last pairs of walking legs long and keeled, tapering but slightly in width towards distal joint, last pair reaching as far as to the telson, metastoma with deep anterior notch.

Type species : *Stylonurus powriei* Page, 1856

2. Genus *Drepanopterus* Laurie, 1892 emend.

Diagnosis.—Stylonuridae of fairly large size, test with acute scales or tubercles, prosoma subrectangular to subovate, lateral eyes with parallel axes, abdomen narrow with styliform to clavate telson, three first pairs of walking legs powerful with spines, two last pairs of moderate length, smooth, tapering but slightly in width towards powerful curved claw, last pair reaching as far as to the penultimate abdominal segment, metastoma unknown.

Type species : *Drepanopterus pentlandicus* Laurie, 1892

3. Genus *Brachyopterus* nov.

Diagnosis.—Stylonuridae of fairly small size, test smooth (?), prosoma large, subtrapezoid to subhexagonal, lateral eyes of slightly anterior position with axes strongly converging forwards, abdomen narrow with rather short styliform, telson, three first walking legs short, of more ordinary eurypterid type with few spines except when modified into clasping organ, two last pairs of moderate length, keeled, tapering in width towards distal joint, last pair reaching as far as to penultimate abdominal segment, metastoma narrow.

Type species : *Brachyopterus stubblefieldi* gen. et sp. nov.

Other species probably belonging to the genus are *Stylonurus pentagonalis* Størmer and ? *Dolichopterus otisius* Clarke.

Description of Species

Superfamily Stylonuracea nov.

Family Stylonuridae Diener, 1924, emend.

Genus *Brachyopterus* nov.

Brachyopterus stubblefieldi gen. et sp. nov.

Text-figs. 1 and 2*d*

Holotype.—D. 3124 of the Geological Survey and Museum, London.

Diagnosis.—The same as for the genus.

Description.—The small eurypterid with an original body length of about 80 mm., is telescoped and flattened in the shaly mudstone. The test probably represents moult-exuvia. The original convexity is unknown.

The comparatively large prosoma has a subtrapezoid to subhexagonal outline with rounded antelateral corners. The length of the posterior margin is about three-quarters the greatest width across the eyes. The

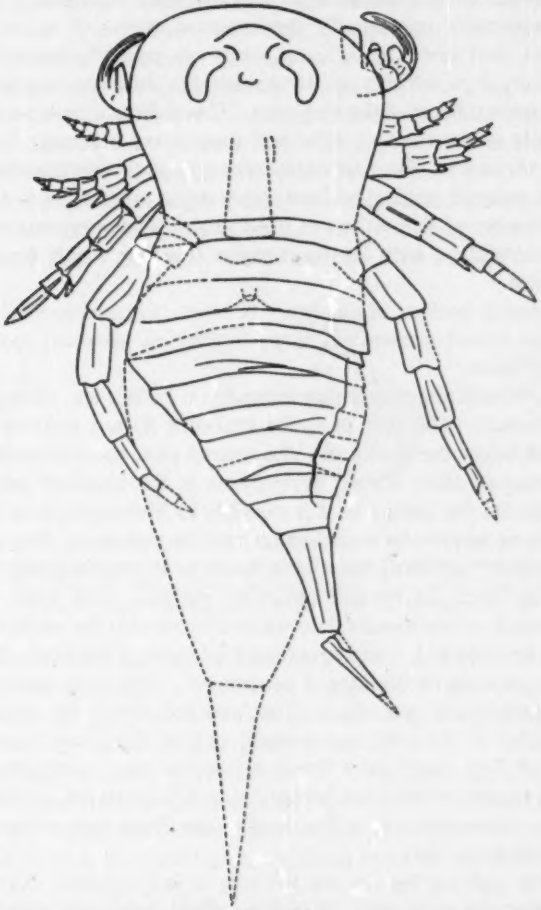

FIG. 1.—*Brachyopterus stubblefieldi* gen. et sp. nov. × 1½. *Diplograptus multidens* zone (Lower Caradoc), R. Severn, N.W. of Bausley House. Drawing based on holotype and counterpart. Dotted line suggests missing parts and actual outline of abdomen.

lateral margins of the prosoma are slightly concave, converging backwards. The prosoma was probably rather flat, a narrow marginal rim is indicated. The arcuate, bean-shaped lateral eyes are situated in the middle of the anterior half of the prosoma, their axes converging

forwards forming an angle of about 55°. Between the anterior portions of the lateral eyes a swollen " glabella ", convex in front, is indicated. Median ocelli are not preserved, but a small round area between the central parts of the lateral eyes suggests their position.

The abdomen, particularly the lateral portions of it, is not well preserved, and since the different joints are partially telescoped into each other, it is difficult to distinguish the different tergites and to make out the outline of the abdomen. The abdomen increases in width backwards to the fourth tergite and then tapers gradually backwards towards the telson. The first tergite seems to be shorter than the others. The five anterior tergites at least, have acute postlateral angles. The actual number of tergites is not observable. The comparatively short telson is styliform with lateral margins tapering evenly towards the distal point.

The ventral surface of the body is practically unknown. In front the dorsal test of prosoma is partly broken off revealing parts of the doublure below.

The prosomal appendages are exposed on both sides of the prosoma and abdomen. The first pair, the chelicera (I) are unknown, being concealed below the prosoma. The second pair, the first walking legs (II), appear as short curved appendages at the broadest part of the prosoma. On the right side it is possible to distinguish four joints of which the proximal one is outlined below the prosoma. The proximal joint, possibly the third, has a long, more or less rectangular, flat lobe protruding from the median (anterior) margin. The next, possibly fourth joint is a little shorter than wide and here also the median margin carries a flat lobe of a width equalling the length of the joint. Probably the distal portion of the lobe is broken off. The next, possibly fifth joint resembles the preceding. The lobe has about the same length as the width of the joint and a small cleft at the distal blunt end is suggested. The distal joint forms a peculiar long sickle-shaped flat lobe, the length of this joint being almost 3/2 the length of the lateral eye. Two lines parallel to the margin run from the proximal joint to the distal blunt end.

The first walking leg on the left side is less exposed, being more curved than the right one. The three distal joints are visible. The first of these, possibly the fourth of the leg, has a long median lobe with a small cleft in the distal blunt end. The length of the lobe is about 3/2 times the width of the corresponding joint. This suggests that the length of the lobes diminishes gradually from the proximal (3rd ?) to the distal (6th ?) joint. The lobe on the next, possibly fifth joint is not well preserved, but seems, like the long, sickle-shaped distal joint, to resemble that on the right appendage.

The first walking leg deviates considerably from what is normally

found in other eurypterids. Unknown in other forms are the flat, broad median lobes and the long, narrow sickle-shaped distal joint. The latter apparently correspond to the two distal joints and the terminal claw in an ordinary leg. When the leg is curved the sickle-shaped distal lobe probably was able to approach and possibly pass above (or below ?) the three flat median lobes.

Somewhat similar structures are found in the clasping organs of certain eurypterids and in the recent horseshoe crabs (Text-fig. 2).

In *Limulus* (Text-fig. 2*a*) the first walking leg of the male has a distal curved lobe opposing a swollen penultimate joint. The two joints form together a clasping organ by which the male attaches itself to the abdominal shield of the female. In the Downtonian eurypterid *Mixopterus kiaeri* (Størmer, 1934) the first walking leg of the male

FIG. 2.—Clasping organs in the Merostomata. *a* = distal portion of first leg in the male *Limulus* (recent), *b* = basal portion of first leg in the male of *Mixopterus* (Downtonian), *c* = second leg in the female of *Eurypterus* (Silurian), *d* = first leg of *Brachyopterus*.

has a similar clasping organ (Text-fig. 2*b*), but in this form the organ is developed at the base, not at the distal end of the appendage. In the female of *Eurypterus fischeri* (Holm, 1898) a clasping organ is found on the second walking leg (Text-fig. 2*c*). A sickle-shaped, longitudinally striated lobe is attached to the fifth segment. Also in *Brachyopterus stubblefieldi* a sickle-shaped lobe is probably attached to the fifth joint, but in this form all the distal joints are completely reduced (if not, the lobe has to be interpreted as the modified distal joints).

The first walking leg (II) of the holotype of *B. stubblefieldi* thus appears to be transformed into a clasping organ of a type similar to those known in other members of the Merostomata.

The second walking leg (III) is small and simple in structure. Four to six joints are known of which the proximal one probably represents the third, the second after the coxa. This joint has no spines, while the three next ones have powerful distal spines at the lateral margin of the subquadratic joints. The distal portion of the appendage is unknown, but was probably similar to that of the third walking leg.

The third walking leg (IV) is larger than the second, but otherwise rather similar. The fourth to sixth joints are powerful with a broad median ridge and a strong lateral spine. Beyond the small seventh joint only the proximal portion of the terminal claw is preserved.

The fourth walking leg (V) is decidedly longer than the third, but at the same time considerably shorter than in members of the genus *Stylonurus*. Five joints representing the fourth to eighth joints are exposed outside the prosoma. The proximal joint, the first after the double trochanter, is parallel-sided with a transverse distal border. The fifth joint is subrectangular in outline, the width increasing slightly towards the distal border. Proximally the joint has a triangular area from the distal point of which runs a median ridge towards the transverse distal border. The distal border protrudes at the continuation of the median ridge. The sixth joints are similar to the fifth, the width increasing slightly more distally. The presence of a distal spine is suggested but not certain. The seventh joint is very short with a median ridge and the width increasing more rapidly towards the distal transverse margin. The eighth joint is long and narrow of practically even width. The terminal claw or ninth segment is unknown.

The fifth walking leg (VI) resembles the fourth but is considerably larger, the length of the eighth distal joint being about 5/3 the length of prosoma. The leg probably reached as far as to about the penultimate segment of the abdomen. The fifth walking leg is not well preserved but the outlines of the joints as well as the longitudinal ridges and grooves are more or less distinct. The two proximal joints disclosed below the abdomen represent the short first and second trochanter, the second and third joints of the appendage (a possible precoxa not counted). The fourth to eighth joints are subrectangular in outline with the width decreasing from joint to joint, the distal joint being very narrow. The length of the joints also decreases more or less gradually.

The lateral outline of the metastoma is faintly suggested below the prosoma. Two lines diverging slightly backwards might represent the inner margin of the posterior coxa, and posteriorly, partly the posterior lateral margins of a narrow metastoma.

Possible traces of a median genital appendage are also suggested.

The test appears to be smooth.

Dimensions.—Length of prosoma, 19 mm. ; greatest width, 23 mm. ; width along posterior margins, 17 mm. ; length of lateral eye, 5 mm. ; probable length of first tergite, 1·8 mm. ; of second, 3·5 mm. ; length of telson, 18 mm. ; approximate length of body, 80 mm.

Affinities.—The relationships of the present form are discussed above in the section on classification.

Occurrence.—Lower Caradoc (Middle Ordovician), in the south

bank of the River Severn, 650 yards N.W. of Bausley House, 1½ miles W.N.W. of church, Abberley, Montgomeryshire.

Associated with graptolites determined by Miss G. L. Elles as *Amplexograptus arctus* Elles and Wood, *A. perexcavatus* (Lapworth), *Lasiograptus* (*Thysanograptus*) *harknessi* var. *costatus* (Lapworth), and *Orthograptus rugosus* var. *apiculatus*? Elles & Wood, indicative of the lower part of the *Diplograptus multidens* zone, shales below the Breidden Dolerite.

New Eurypterid Genera substituting previously Preoccupied Genera

Family Stylonuridae Diener, 1924

Genus *Tarsopterella* nom. nov.

Synonym: *Tarsopterus* Clarke and Ruedemann, 1912, p. 287.

Type species: *Stylonurus scoticus* Woodward, 1864.

The genus *Tarsopterus* was introduced by Reinhard and Lütken for an amphibian (*Vidensk. Meded. naturh. Foren.*, Kjøbenhavn, 1862). (Neave, 1939–1940.)

Family Eurypteridae Burmeister

Genus *Onychopterella* nom. nov.

Synonym: *Onychopterus* Clarke and Ruedemann, 1912, p. 212.

Type species: *Eurypterus kokomoensis* Miller and Gurney, 1896.

The genus *Onychopterus* was introduced by Reichenback for a bird (*Avium Syst. Nat.*, pl. LXV, 1850). (Neave, 1939–1940.)

Genus *Tylopterella* nom. nov.

Synonym: *Tylopterus* Clarke and Ruedemann, 1912, p. 216.

Type species: *Eurypterus boyli* Whiteaves, 1884.

The genus *Tylopterus* was introduced by Capiomont for a coleopterid (*Ann. Soc. ent. France* (4), 7, 1867). (Neave, 1939–1940.)

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Mylonite, Slickensides, and the Great Glen Fault[1]

By S. J. Shand

Abstract

It is shown that mylonite is extremely rare in the plane of the Great Glen fault, and that horizontal slickensides or friction-grooves directed along the Glen are virtually absent. Grave doubt is consequently thrown on the alleged horizontal displacement in the fault zone.

THE opposed surfaces of a fracture in hard rocks, if they are strongly pressed together and at the same time compelled to slide over each other, must inevitably develop mylonite in the fault plane. Professor Kennedy clearly recognized this when he wrote in his brilliant paper on the Great Glen Fault (Kennedy, W. Q., 1946, p. 55) that

> " mylonites may be expected to form along directions *across which the pressure is intense* " (Kennedy's italics).

In his discussion of the general features of the faulted belt (p. 45) Kennedy stated that—

> " the line of disruption is marked by a broad belt of crushed, sheared, and mylonitized rock up to about a mile in width ".

On the same page he said that—

> " the ultimate products of the dislocation metamorphism are represented by true mylonites and flinty-crush rocks."

With regard to slickensides Kennedy wrote (p. 57) that the faults of the system to which the Great Glen belongs—

> " frequently show evidence of lateral movement such as horizontal slickensides."

From his discussion of the physical characters of the fault-line (pp. 54–7), it is clear that Kennedy attached great importance to the evidence of mylonite and slickensides. With this the present writer heartily agrees, his own experience in the field having impressed on his mind the significance of these accompaniments of movement. He was therefore surprised, on his first visit to the Great Glen, to see neither mylonite nor any horizontal slickensides. This seemed to the writer to throw doubt on the alleged horizontal displacement, so he discussed the matter with Professor Kennedy, who repeated the warning already given in his paper (p. 45) that—

> " most of this zone is concealed by the deep superficial deposits of the Great Glen or the waters of the lochs."

Nevertheless the writer was so impressed by the desirability of testing in every way the evidence for this extraordinary fault that he undertook for his own satisfaction, to make a search for mylonite and slickensides from end to end of the Great Glen. The undertaking was carried

[1] Communicated to the British Association for the Advancement of Science, Section C, 13th August, 1951.

out during portions of three successive summers, and this paper is intended to convey the results of the search.

It should be stated, in the first place, that the conditions of exposure are by no means so bad as Professor Kennedy thought. There is now such a volume of motor traffic along the Great Glen that the main roads have been widened and there are many large fresh road-cuts and small quarries which afford admirable exposures, especially on the north side of Loch Ness and on both sides of Loch Linnhe. Again, although most of Loch Ness is over a mile wide, the width of the submerged zone diminishes at Fort Augustus to three-quarters of a mile and at Bridge of Oich to only one-third of a mile. At the latter locality the buried strip is bounded on the north by some of the cleanest natural exposures of Moine gneiss that are to be found anywhere in the Glen. This narrowing of the buried zone is due to a ridge (called Torr a' Choiltreich on the 1-inch map) which brings the gneiss up through the alluvium in a strip three miles long and a third of a mile wide, *directly in line with Loch Oich and Loch Ness*. This ridge consequently exposes the very material that must underlie Loch Ness at its south end. Further down the Glen, Loch Oich is only a quarter of a mile wide and the rocks that flank it are exposed both by nature and by road-cuts. It seems to the writer that the Fort Augustus–Loch Oich area is critical for the study of the Great Glen fault.

About Loch Lochy the exposures are relatively poor, and plantations cover much of the north and south hillsides right down to the water's edge. There is no road on the north side of this loch. At the south-west end of Loch Lochy the Spean River enters the Glen in a deep gorge which affords admirable exposures of the country rocks south of the River Lochy. From Banavie and Glen Nevis onward there are good natural exposures and road-cuts along both shores of Loch Linnhe as far to the south-west as Onich and Glen Tarbert.

It will be convenient to discuss first the evidence of slickensides and friction-grooves, and thereafter the occurrence of mylonite. In relating these personal observations and the deductions drawn from them it will be advisable in the interest of clarity to use the first person singular.

Slickensides and Friction-grooves

Apart from Kennedy's general statement about horizontal slickensides (quoted above) there seems to be only one reference to such slickensides in the neighbourhood of the Great Glen. E. Cunningham Craig reported (1914) that in the gorge of the Allt Mor, about 3 miles west of Inverness and parallel to the direction of Loch Ness,

> "horizontal striations prove that lateral movement took place along this line of disruption."

Conditions must have been more favourable in 1914 than in 1950,

for I found the gorge so obstructed by trees and brushwood, and the rocks so rotten and moss-covered that I could make no observations of any value. The only suggestions of horizontal movement that I saw were transverse to the direction of the Great Glen.

Along the north shore of Loch Ness the Abriachan granite and the Old Red Sandstone are much fractured. I use the word *fractured* in preference to *crushed* because crushing involves movement perpendicular to some direction of compression, and of this I have seen no sign. Many of the surfaces of fracture show shallow grooves or striations, but these striations almost invariably have a greater vertical than horizontal component (the commonest dip is about 70°), and they are generally directed *across* instead of along the Glen. I attach little significance to these minor slickensides, but more to certain larger joint surfaces which have been laid bare by quarrying. These surfaces, which in a few instances exceed 100 square yards, are nearly vertical and they strike up and down the Glen ; yet they show no grooves or striations at all. It is precisely on such surfaces as these that we might have expected to find horizontal striations.

About Loch Oich and Loch Lochy the Old Red Sandstone is much fractured, but I observed little evidence of movement or compression in any particular direction, least of all the horizontal direction. To my mind the evidence suggests collapse of the sandstone into a fault-trough.

In the Moine gneiss, shallow grooves and striations are often present on the under surfaces of flaggy beds. They follow the dip and change direction as the strike changes, so they seem to be connected with the folding of the Moine and not with any fault.

In short, after examining hundreds of slickensides and striated surfaces in all parts and in all the rocks of the Great Glen, I have failed to find any evidence of movement in the direction required by the hypothesis of transcurrent faulting.

Mylonite

This was the main object of my search, and I have to report an almost complete failure to find any of it. In a large area where outcrops are often concealed by scree, bog, heather, grass, and bracken, as well as by the plantations of the Forest Department, and where visible surfaces of rock may be mantled with moss or lichens, one may easily miss the object of such a search ; but at least I can claim to have searched the floor and the lower slopes of the Great Glen more thoroughly than anybody else has attempted to do. No question of geological interpretation is involved—one either finds mylonite or one does not find it—and for such a search it is not necessary to have any wide knowledge of Highland geology such as Professor Kennedy

possesses. I am a novice in the latter respect, but I may claim to have a more intimate acquaintance with mylonite and its appearance and behaviour than most geologists, for I was the first to make a study of the remarkable development of mylonite (pseudotachylyte) in the Parys district of the Orange Free State (1916, p. 198). While I was walking over the outcrops of gneiss near Bridge of Oich the thought was constantly in my mind that in an equal area of gneissic rocks round about Parys I should have seen literally hundreds of veins of pseudotachylyte or fritted mylonite resulting from the uplift of the Vredefort dome.

In the entire length of the Great Glen I failed to locate a single megascopic vein of mylonite. (I thought I had located one at the mouth of Glen Gour, but a thin section showed it to be a sheared basic dyke.) All I can record is a few microscopic veinlets of mylonite in thin sections of Moine gneiss. They are parallel to the lamination of the gneiss ; they are about a millimetre wide, and they pinch out in a couple of centimetres. Such veinlets might be found in any hard rock that has been strongly folded. There is no known reason to relate them to the Great Glen fault.

Kennedy reported the discovery by Mr. V. A. Eyles of mylonite in some of the gorges that break through the south wall of the Glen about Laggan. Mr. Eyles kindly permitted me to examine his specimens and the thin sections that have been cut from them. Among them are garnetiferous and other varieties of the Moine gneiss, some that may be arkose or granite, others that may be quartzites, sandstones, or siltstones. Many are obscured by carbonates and sericite. One or two specimens of gneiss show microscopic veinlets of mylonite such as I mentioned in the last paragraph. Since the geological relations of these rocks are quite unknown (owing to the unsatisfactory nature of the exposures) they can hardly be considered to throw any light on the problem of the Great Glen fault. It is not enough to say that " mylonite has been found in the Great Glen ", as if that settled the question ; one must study the orientation of the mylonite veins and demonstrate a probable connection with the N.E.–S.W. faulting rather than with folding of the Moine. This has not been done by Kennedy or his supporters.

Kennedy also reported the discovery of mylonite by Dr. Drever, on the north side of Loch Linnhe. No details of this discovery have been made public, but Drever tells me that " the planes of shearing were not vertical but tended to be fairly flat ".

Dr. Pochin Mould recorded in 1946 that the Foyers granite in Glen Liath is " traversed by many crush zones and movement lines ", but gave no details and failed to indicate the orientation of these lines of movement.

In conclusion it must be said that if these few trivial occurrences of mylonite were multiplied a thousandfold they would still fall far short of the requirements of Kennedy's hypothesis and of his claim that there is in the Great Glen " a broad belt of crushed, sheared, and mylonitized rock up to about a mile in width ".

The Spean Gorge

The Spean River, flowing N.W., joins the River Lochy at Mucomir, near the S.W. end of Loch Lochy. All the way from Spean Bridge to the Falls of Mucomir the deeply incised gorge affords continuous exposures of beautifully bedded mica schist, or thin-bedded quartzite with micaceous partings. Strike and dip are remarkably constant, and there is nowhere any sudden change such as a great transcurrent fault with a broad zone of crushing and shearing might be expected to produce. If there is such a fault, it must be concealed beneath the half-mile wide strip of alluvium that lies north-west of Mucomir.

The Significance of Mylonite

It remains to discuss the significance of mylonite in relation to faulting. Kennedy himself argued (1946, p. 55) that—

> " The occurrence of mylonite in the shear-zones of the San Andreas and Great Glen faults . . . indicates clearly that, at the time of dislocation, intense pressure was developed across the fault planes. Such a condition, indicating compression during movement, could only apply in the case of wrench-faulting of the type postulated and leads to the conclusion that the predominant displacement along the Great Glen fault was horizontal."

Does not this conclusion involve some proportionality between the magnitude of the displacement and the amount of mylonite formed ? Can there be tremendous wrench-faulting with little or no development of mylonite ? Surely not, at least in hard rocks. A fracture more than 130 miles long in a complex of unequally resistant rocks such as gneiss, schist, and quartzite, friable sandstone and massive granite, cannot be pictured as a straight crack with smooth surfaces, between which movement might take place with little friction. Kennedy has described the dislocation as " a *zone* of intense and intricate faulting and shearing rather than a single well-defined fracture " (1946, p. 45). Movement to the extent of 65 miles along such a zone could not be accomplished without a tremendous production of mylonite of every grade from coarse fault-breccia to the finest ultramylonite.

Turning to the San Andreas fault, which Kennedy cites as a parallel case, we learn from L. F. Noble's report (1925–6, p. 415) that—

> " One noteworthy feature of the fault-zone is the thorough crushing and shattering of the harder rocks everywhere along the

main fault, usually through a belt several hundred yards wide. In this belt the rocks are at most places so ground up that they are practically gouge."

On the same subject Waters and Campbell (1395, p. 473) report that—

" mylonite occurs as a sort of matrix which encloses the other rock varieties. Locally it forms great tabular masses many feet in thickness."

Surely it is not necessary to refer at length to the immense development of mylonite (pseudotachylyte) in and around the Vredefort dome (Hall and Molengraaff, 1925; L. T. Nel, 1927); to the 75-mile belt of mylonite in the outer Hebrides (Jehu and Craig, 1923–1934); to the mylonites that accompany the thrust-planes of the Alps and the Himalaya; to the mylonite belts of Georgia and Pennsylvania, or those that have been described this very year from Goldfields, Saskatchewan (Conybeare and Campbell), and from Ruwenzori (Johnson and McConnell)—in order to compel the conviction that movement under great pressure in hard rocks must generate abundant mylonite?

I feel that the extreme scarcity of mylonite in the Great Glen is irreconcilable with the hypothesis of a gigantic horizontal displacement. I gladly pay tribute to Professor Kennedy's courage in advancing such a startling concept; to the brilliance of his advocacy; and to his courtesy and broad-mindedness in discussing the matter with me; yet I feel that we have here another illustration of what Huxley called

" the great tragedy of science; the slaying of a beautiful hypothesis by an ugly fact."

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A Note on the Occurrence of Intergrowth between Diopsidic Augite and Albite and of Hydrogrossular from King Island, Tasmania

By Beryl Scott
Geology Dept., University of Tasmania

(PLATE XIII)

Abstract

A description is given of an intergrowth between augite and albite found in Spilitic lavas from King Island, Tasmania. Hydrogrossular is found pseudomorphing olivine and also in veins and vesicles in certain rocks of the same volcanic suite.

OUTCROPPING along the south-eastern coast of King Island in Bass Strait, Australia, is a suite of volcanic rocks reputed to be Middle Cambrian in age.

The rocks occur in the form of massive, pillow, pahoehoe, and aa lavas accompanied by fragmental rocks such as breccias and tuffs. Chemically the rocks fall into two groups, spilites and picrite basalts.

The massive lavas may be further subdivided into two types, a normal basaltic type and an ophitic type. It is with the latter that this note is concerned. The petrology of this volcanic suite has been described recently by the author (Scott, 1951) and it is to this work that the reader is referred for greater detail.

The ophitic type of massive lava consists of large plates of augite which are pierced by small laths of plagioclase. The augite is colourless and is extremely fresh except for slight alteration to a brown mineral around the edges. The birefringence is ·030. The mineral is biaxial positive with an optic axial angle of 51° and an extinction angle of 40°. These properties indicate a diopsidic variety. Some of the large plates of augite have been so broken up by the presence of the plagioclase that they appear to consist of numerous small augite grains and it is not until the mineral is observed under analysed light that it is realised the mineral plate is homogeneous. The plagioclase is almost pure albite, $Ab_{98}An_2$, and has been partly altered to sericite.

Another phase of this type of basalt gives rise to an unusual and interesting rock. Microscopically, the rock consists for the most part of two minerals, diopsidic augite and a felspar which has been mostly pseudomorphed by sericite and some chlorite, although small patches of unaltered felspar remain. As usual the diopside is quite fresh and has similar properties to those described above. It forms homogeneous plates which are broken only by the presence of the plagioclase. The unaltered patches of plagioclase indicate almost pure albite. The amazing feature of the rock is that the diopsidic augite and albite form

perfect intergrowths covering the whole field of the microscope. The intergrowth has not taken place in any definite crystallographic direction.

Benson (1915) described spilitic rocks from the Nundle District, New South Wales, in which fresh augite was ophitically grown about albite. In this case he believed the albite to be primary. The author is unaware of a description to date in the geological literature read, of a similar intergrowth between these two minerals and she feels she can be more assured in claiming that some of the albite in the King Island spilitic rocks is primary. In other types of volcanic rocks in the suite the albite appears to be of late magmatic origin, the result of albitization of a basic plagioclase. However, Professor C. E. Tilley of Cambridge, in a personal communication to the author, suggested that the intergrowth may have been originally between augite and a basic plagioclase and albitization followed later.

In the same volcanic suite is a new occurrence of hydrogrossular which to date has only been described as associated with basic and ultrabasic intrusions (Hutton, 1943). Here it is found to be pseudomorphing almost perfect idiomorphic phenocrysts of olivine and in some cases the plagioclase. It is also found in veins and vesicles where it has a concretionary form and the various members of the hydrogarnet series can be recognized by the differently coloured concentric layers and varying refractive indices (i.e. n = 1·663 to 1·753). A great proportion of the glass in the breccias has been converted to hydrogarnet and in some rocks, especially the picrite basalts, the hydrothermal solution containing this mineral has attacked the groundmass thus converting it into hydrogarnet.

A chemical analysis of an average powder of the various members of the hydrogarnet series yielded the following result :—

SiO_2 . . .	37·28
Al_2O_3 . . .	23·11
Fe_2O_3 . . .	5·26
FeO . . .	0·73
MgO . . .	4·12
CaO . . .	27·44
Na_2O . . .	n. dt
K_2O . . .	n. dt
H_2O+ . . .	1·37
H_2O- . . .	0·44
TiO_2 . . .	0·06
MnO . . .	n. dt
	99·81

The chemical composition, based on the general formula $X_2Y_2(ZO_4)_{3-m}(OH)_2$ (McConnell, 1942), was determined to be $(Ca\ Mg\ Fe'')_{2.631}(Al\ Fe'''Ti)_{2.068}((Si,\ Al)O_4)_{2.833}(OH)_{.667}$.

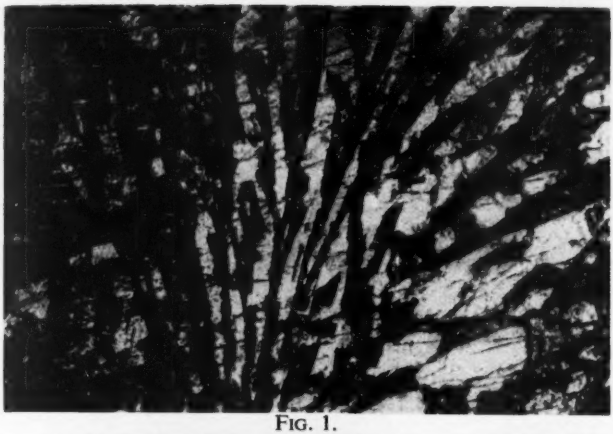

FIG. 1.

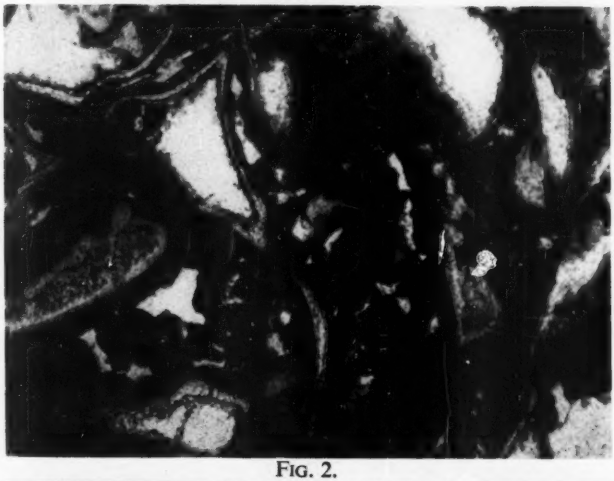

FIG. 2.

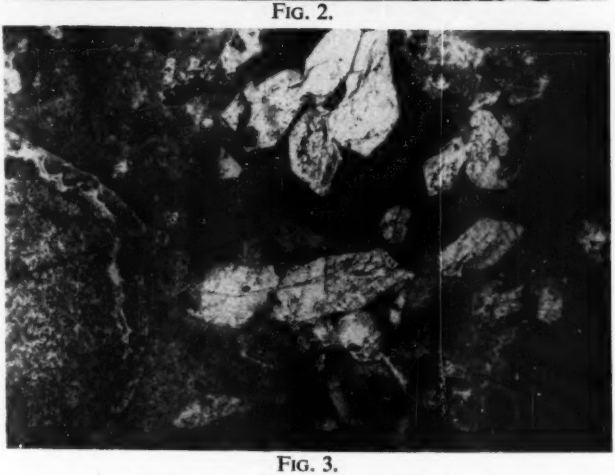

FIG. 3.

AUGITE–ALBITE INTERGROWTH AND HYDROGROSSULAR, KING ISLAND, TASMANIA.

X-ray data were determined from an X-ray powder photograph of the hydrogrossular taken on a 9 cm. Unicam camera using copper radiation and a nickel screen. The three strongest lines are d = 2·689, 1·607, 3·026, and the cell size is 12·03 Å.

The hydrogrossular in the King Island basic volcanic rocks is a hydrothermal mineral. It is associated with other lime-rich hydrothermal minerals and has been formed, most probably, from the lime and alumina set free during the albitization of the basic plagioclase and the introduction of these constituents from nearby granite.

Details of this mineral and its occurrence are given in the account of the petrology of the volcanic rocks (Scott, 1951).

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EXPLANATION OF PLATE XIII

FIG. 1.—Spilite showing intergrowth between diopsidic augite and albite which has been greatly replaced by sericite. The albite is at extinction.

FIG. 2.—Volcanic breccia showing glass fragments replaced by chlorite and hydrogrossular. The hydrogrossular can be recognized as the darker mineral around the edges of the fragments contrasted with the light coloured chlorite. The dark material between the fragments is also hydrogrossular.

FIG. 3.—Picrite basalt showing the occurrence of hydrogrossular in a large vesicle and as a replacement of some of the olivine phenocrysts as recognized by the dark patches. The groundmass is very fine grained consisting of tremolite and augite and it too has been partly converted to hydrogarnet in the darker shaded areas.

Sorting of Lamellibranch Valves on Beaches in Trinidad, B.W.I.

By P. Martin-Kaye

Abstract

Marked differences in relative abundance of right and left valves of certain recent lamellibranchs are recorded in collections made along beaches of eastern Trinidad, and a possible explanation is discussed.

THE collection of numerous specimens of the spined marine lamellibranch *Pitar dione* Linné from a beach on the eastern coast of Trinidad, B.W.I., led to the discovery that at this particular locality the right valves are very much more common than the left, the ratio exceeding 4 : 1. Further collections from the same place showed that this ratio varied but little on each occasion and that the phenomenon is also displayed in a species of *Arca*, tentatively determined as *Arca incongrua* Say, although in a somewhat less marked degree. On the other hand, right and left valves of *Tivela mactroides* Born. were found to be more or less equally abundant.

The possibility of this unequal distribution in *Pitar* and *Arca* being due to an accident of collection was precluded by the number of specimens involved. Obviously some agent of selective sorting has been operative. In order to determine whether this feature was local or widespread, a series of collections of these two species was made over some thirty miles of the southern half of the eastern shore of the

I. Cocos Bay

	Pitar dione		*Arca incongrua*	
Locality	*Total No.*	*% Right Valves*	*Total No.*	*% Right Valves*
1	45	11	122	36
2	154	13	362	30
3	11	18	432	46
4	51	ca. 50	315	85
5	73	ca. 50	313	86
6	284	46	316	71
7	27	ca. 50	295	81
8	450	87	165	60

II. Mayaro Bay

	Pitar dione		*Arca incongrua*	
Locality	*Right Valves.*	*Left Valves.*	*Right Valves.*	*Left Valves.*
9	2	—	—	3
10	27	19	10	6
11	4	4	1	—
12	24	27	5	7
13	35	40	5	8

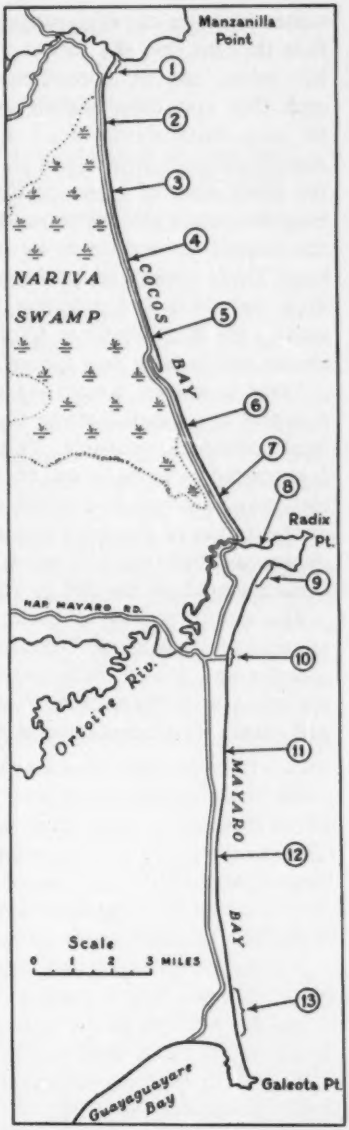
island ; the various localities to which visits were paid are indicated on the accompanying sketch-map.

Unfortunately beach shells are not uniformly abundant, and on some occasions the numbers obtainable were insufficient for the purposes of accuracy. Particularly was this the case with Mayaro Bay but, on the other hand, Cocos Bay generally provided large enough collections to render the results conclusive. Details of the collections are tabulated on p. 432.

From Table I it is apparent that left valves of both species were dominant at the north of Cocos Bay, but from localities 4 to 7 there was a divergence of behaviour, the two valves of *Pitar* being more or less equally represented whilst in *Arca* the right outnumbered the left.

Table II seems to indicate that there were no large shell beds in the immediate vicinity of Mayaro Bay or, at least, that conditions were not suitable for specimens to be cast ashore in large numbers. So far as the small totals can be relied upon they appear to show a more or less equal representation of both valves throughout, although perhaps there is a faint suggestion of a reversal of the situation north of Radix Point.

The rather limited amount of literature on Recent beaches available to the writer contains no reference to the sorting of lamellibranch valves such as is found in Cocos Bay. Fossil deposits in which one valve of the shell is more common than the other are known, although so far as the



TEXT-FIG. 1.—Sketch Map of the southern part of the eastern coast of Trinidad, B.W.I., showing localities from which collections were made.

writer is aware no explanation for this peculiarity has been offered. It is thought that the reason may lie in the fact that the right and left valves are, of course, mirror images of one another. Being such they may differ slightly in their response to the forces tending to move them shorewards : the opposite symmetry may favour a slightly different direction of travel in each case. It is easy to imagine the offset rows of spines in *Pitar dione* assisting in such a process. Separation may possibly proceed further on the beach itself as the shells are washed up and down by each succeeding wave. On the other hand *Tivela mactroides*, possessing a rounded equilateral shape, offers little on which such selective tendencies could operate, which may explain the 50 : 50 ratio at Radix Point in contrast to the inequalities shown by the other two species.

Little is known concerning currents operating along this coast ; that they are complicated by the presence of the headlands and shoal banks offshore is probable. Tide rips are known to exist and the beach is subjected to more or less continuous and often heavy surf. Cocos Bay may be a rare case where currents, location of shell banks, and configuration of the shore line are all favourable. Possibly, however, an unequal distribution of valves on embayed coasts is a fairly common occurrence which has not as yet attracted attention.

The author wishes to thank the Draughting Department of the Geological Division of Trinidad Leaseholds, Ltd., for preparing the sketch-map ; Dr. H. Bolli and Mr. I. Duiguid for assisting to collect material ; and Professor A. Wood of the University College of Wales and others for their comments and suggestions.

Notes on Erosion Along the Coast of Suffolk

By J. A. Steers

Abstract

Comparison of the Suffolk coast with dated large-scale Ordnance Survey maps indicates regions where noticeable erosion or accretion has occurred during the past quarter of a century. It is important to establish why and how the incidence of erosion varies with time and place.

In June, 1950, Mr. A. T. Grove, Mr. H. W. West, and I made a series of measurements in order to establish the nature of coastal change that has taken place in recent years along the Suffolk coast. It is not by any means easy to do this with any precision since the large-scale ordnance maps only mark the edge of the cliff and high and low water marks. The cliff is hachured, and although the upper edge may be assumed to be correct, the lower can in many cases only be a matter of opinion rather than fact, since the cliff material sometimes grades out very gradually into beach, in other places may be temporarily obscured by a slip, and often enough covered by blown sand. Hence, accurate measurements of the volumetric loss are almost impossible to make under these circumstances. The measurement to high water mark of ordinary tides is also ambiguous. It implies strictly that the line of H.W.M.O.T. should be re-established before the next measurements are made. But on the flat sandy stretches or on wide beaches the line itself even when surveyed carefully can have little precise significance, and subsequent changes in the beach completely nullify it. Hence, all direct measurements of this type are subject to certain unavoidable errors. In addition there are also minor sources of inaccuracy. Measurements from fixed points such as the corners of buildings or other permanent structures are usually easy and direct. On the other hand to measure from, say, a hedge or field corner on the six-inch map can easily give rise to an error of a foot or two, since the growth of the hedge or similar cause makes it difficult to establish the actual line or point which was originally surveyed.

Subject, however, to slight errors of these kinds, our survey has shown that the loss of land along parts of the shore is serious and in some places continuous. Most of the existing Ordnance maps are based, as far as the coast is concerned, on a revision made in 1925 or 1926. A few maps were revised in 1938, but the coast was not included. The maps covering Orfordness (not included in our own measurements) have not been revised as far as the coast is concerned since 1902.

Between Yarmouth and Lowestoft there has not been much change. The sea wall at Gorleston now reaches as far south as Links Road, and has stabilized the coast to the north. Southwards from that

point erosion has been fairly severe at Hopton. The recession of the cliff top has been between 60 and 80 feet, averaging from two-and-a-half to rather more than three feet a year. At Corton there seems to be little change: the severe erosion of earlier years has, at any rate temporarily, ceased.

No measurements were made at Lowestoft itself, but the breaking and undermining of the sea wall north of the harbour and its present rebuilding are sufficiently indicative of the conditions. At Pakefield the erosion has been held by new walls, but to the south the cliff-top has receded at least as far south as Pakefield Holiday Camp; the loss lies between 50 and 70+ feet in 24 years (1926–1950), giving an annual loss of two to three feet.

Kessingland cliffs lie behind an extensive accumulation of beach which has changed little since 1925. There is certainly no cliff erosion. Nearer to Kessingland Beach erosion was severe but is now stopped by a sea wall which has been built to a point some 1,750 feet north of the Lifeboat House. Quite locally there is erosion at the north end of the wall. To the south of the Lifeboat House the wall extends about 1,300 feet, but at least the southern half of this is now well protected by beach. Groynes have also been built at Kessingland Beach, and they clearly testify to a local but definite northward drift of beach material.

Big changes have taken place between Kessingland and Benacre Broad. In 1925 Benacre Ness, the most easterly part of this stretch, was almost due east of Beach Farm. Since then the most easterly point has shifted some 1,600 or 1,700 feet to the north, and the coast for a considerable distance on either side of the sluice has prograded. At the sluice it amounts to about 400 feet. On the other hand, erosion has been particularly severe southwards from the Ness Point of 1925–6. The sea occasionally breaks in to Benacre Broad and for a distance of about half a mile a strip about 600 feet wide has been lost; it will not be long before the sea reaches the New Cut.

Erosion is still very serious at Covehithe, and at the road running to the coast from the village has averaged 17 feet a year since 1925. Off Green Heath, The Warren, and Easton Broad, the loss is continuous but lessening gradually to the south. From the north end of the Warren to the northern part of Easton Broad it amounts to between 300 and 350 feet in 25 years but this gradually falls to nil at Southwold Pier.

No measurements were made along the protected area at Southwold except one immediately north of the harbour. The accretion which has taken place there seemed to me to be less than a year ago, but this impression is not based on measurements. The changes made at the South Pier during the war and the subsequent damage to both North

and South Piers by the sea easily account for the known changes in the beach north of the North Pier, and have given rise to a good deal of controversy.

Southwards from the harbour erosion gradually increased to a maximum of 270–280 feet off Corporation and Reedland Marshes (average annual loss 10–11 feet). It decreases to nothing at the north end of Dunwich cliffs, which near the Coast Guard Station have changed negligibly since 1925. Southwards from the Grey Friars Monastery erosion begins again but is not excessive. At Grey Friars the cliff recession is 25 to 30 feet, at Grey Friars Wood 50 to 60 feet, off Dunwich Common about 40 feet. At Minsmere Cottages it is similar and just south of the cliffs is more serious. Coney Hill has disappeared and the sea is liable to flood up to the sea wall.

The position of Dunwich is, and always has been, one of great interest from the point of view of coastal erosion and accretion. To-day there is erosion to the north and to the south, while at Dunwich itself there has been comparatively little in recent years. It must be realized that both to north and south are extensive marshlands which are, in effect, only protected by shingle beaches. In Corporation Marshes and at Coney Hill these beaches have been breached and, under natural conditions are likely to be overwashed with considerable frequency in storms. Thus the whole marshland north and south of Dunwich is extremely vulnerable. Seawalls and extensive groyning have been proposed but the expense is very great. In Minsmere Level there are extensive agricultural lands and several embankments; there is little doubt that this is the more important area to protect. The northern marshes are attractive, but have been little used, and from the purely agricultural point of view are far less valuable. However, the point remains that Dunwich cliffs stand between two very vulnerable areas, both of which if nothing further is done are liable to inundation at some future date. Whilst a severe storm might easily inundate large areas of either of these marsh districts, there is no reason to suppose that they would be flooded sufficiently to enable serious wave action to take place at their inner limits until such time as a series of storms made breaches wide and low enough for standing water to remain on the marshes at all stages of the tide. It is far more likely that the conditions that occurred in recent storms will be repeated for some time.

South from Coney Hill there is very little change from the conditions shown on the existing maps. There appears to have been slight erosion of the dunes, but changes of that sort could take place many times and be healed again by blown sand. At Sizewell the cliffs run behind a wide sandy foreland and consequently they show no change. This also seems to be true of the dunes, apart from quite

local erosion, until Thorpe Ness is reached. The current (1950) six-inch map shows a wide projection (about 600 feet as measured from the cliff top) at this point. This has largely disappeared and the general line of the coast continues right through from Sizewell to Thorpe Ness. In short, the former 600 feet wide foreland is now only 200 feet wide. But the conditions of dunes and vegetation all suggest that at the time of our visit erosion had ceased and that accretion was in progress. South of Thorpe Ness there is a little accretion and the beach becomes far more shingly. However, there is no measurable change until the north end of the new sea wall at Aldeburgh.

Aldeburgh has been subject to severe erosion in the fairly recent past, but extensive protection walls have been built and are being extended. These are particularly necessary, especially at the central and southern parts of the town. At the southern extremity of the wall the coast makes a steep landward bend, testifying to what would have happened farther north if the wall had not been there. The outer wall of the Martello Tower just south of Slaughden has been breached by the waves and erosion continues some way to the south, but no measurements were made beyond the tower. This erosion continues the long and slow process of the great shingle bar being pushed gradually landward, but is made more obvious by the buildings it has already wholly or partially obliterated, and by those that are still threatened. Since the southern part of the town is backed only by marshland a breach would be serious. New groynes have been built between the town and the Martello Tower, with good effects. The conditions already noticed at Kessingland repeat themselves here. Locally the groynes point to a reversal of beach drift which in the groyned stretch now appears to go to the north. There is no satisfactory explanation of this—but it serves to emphasize the importance of avoiding generalization on this subject.

No measurements were made on the great shingle bank of Orfordness.

At Shingle Street there has been some loss. In front of the Street the present high water mark (estimated) is in one place 270 feet within that given for 1925. This lessens to the south and opposite the second Martello Tower is replaced by accretion of about 100 feet. At the third tower the accretion amounts to 150 feet. This decreases gradually and immediately after passing the seaward end of Beach Lane, Bawdsey gives place to marked erosion which, however, is restrained by considerable defence works. At the fourth Martello Tower there had been a loss of the order of 160 feet—approximately six feet a year.

This has continued farther to the south, and opposite Bawdsey Hall the recession of the cliff edge amounted to about 100 feet. In a few hundred yards, however, the erosion of the cliff edge, apart from local slips, had virtually ceased, and the last measurement we made

opposite the lodge leading to Bawdsey Manor showed very little change.

This brief summary indicates the variation of conditions along the coast. Cliffs like those behind the beach accumulations at Kessingland, Sizewell, and Thorpe Ness are at present protected : others show but little change, e.g. Dunwich. Others again, especially at Covehithe, show marked loss. Similarly the areas of accretion differ considerably from those in 1925–6. Benacre Ness is well to the north of its former position, and there has been some gain off Kessingland Level, more than balanced by severe loss off Benacre Broad. On the other hand, loss at Shingle Street is largely made good by greater accretion nearer Bawdsey.

Comparisons have been made with dated Ordnance maps. It is possible that considerable changes have taken place in the last 25 years, and that no record of them now remains. A quarter of a century is time enough for erosion to give place to accretion at a place, and for that place, as far as measurements are concerned, to show no change.

I am indebted to the Director-General of the Ordnance Survey for certain information about dates of map revision. The Nature Conservancy generously covered certain expenses.

[*N.B.*—Since this survey was made, new editions of the six-inch map are available. Unless this is remembered readers may obtain a false impression of figures and averages.]

CORRESPONDENCE

FURTHER RENAMING OF THE TREMADOC TRILOBITE GENUS *PSILOCEPHALUS* SALTER

SIR,—In the May–June number of this magazine (Stubblefield, 1951) attention was drawn to three vain attempts by previous authors to give a nomenclatorily valid name to the generic concept typified by *Erinnys venulosa* Salter 1872 and to Salter's earlier likewise vain attempt with his species *Psilocephalus innotatus*. In an effort to remedy these nomenclatorial mishaps, the names *Meneviella* and *Psilocephalina* were proposed as *nomina nova*. It seems, however, that the second name is also invalid for on 11th September, 1951, a copy was received in the Geological Survey Library of No. 8 of the "Contributions from the National Research Institute of Geology, Academia Sinica" which is a "Festschrift" volume to commemorate the sixtieth birthday of Professor J. S. Lee. This work has printed on its cover "November 1948" as the date of publication. Presumably, the politically disturbed state of China has contributed to the delayed arrival in London of this volume. Among the interesting papers within its covers is one by Singwu C. Hsü (1948), in which a new genus of trilobites named *Psilocephalina*, with *P. lubrica* Hsü as type species, is described from strata in Western Hupeh stated to be of Tremadoc age. Following the generic diagnosis, Hsü (op. cit., p. 24) remarks that his new genus "bears a close kinship to *Psilocephalus* Salter . . . , a characteristic genus occurring in the Tremadoc beds of Britain. It is similar to Salter's genus in the small anterior palpebral lobes and in the characters of the fixed cheeks and the thorax but differs in having genal spines and a wider axis of pygidium. Its free cheeks are also different in general shape from those of Salter's genus. . . . It is very likely that the present genus is a vicarious form of the British genus *Psilocephalus* in this continent". Judging from the description and illustrations, the cranidium of the type species of Hsü's new genus is certainly morphologically similar to that trilobite which lately (Stubblefield, 1951) was referred to *Psilocephalina innotata* (Salter), I being unaware that the generic name had been employed by Hsü in 1948.

Of the two available alternative courses, namely either to consider the Welsh *P. innotata* to be congeneric with the Chinese *P. lubrica* or to follow Hsü in his opinion that the species are generically distinct, the latter is here preferred. Both species belong to genera in which the obsolescence of cephalic furrows has masked those axial skeletal features usually available for comparison, so that one is hesitant to dismiss as unimportant the obvious differences in structure of the respective free cheeks. Accordingly, it is here proposed that the name *Borthaspis* (after Borth-y-Gest, Merioneth, the locality of the lectotype of the type species *Psilocephalus innotatus*) replaces the junior homonyms *Psilocephalina* Stubblefield (1951, p. 213) *non* Hsü (1948, p. 23) and *Psilocephalus* Salter (1866, p. 315) *non* Swainson (1839).

C. J. STUBBLEFIELD.

GEOLOGICAL SURVEY AND MUSEUM,
SOUTH KENSINGTON, LONDON.
20th September, 1951.

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A SIGNPOST MEMORIAL TO WILLIAM SMITH

SIR,—A " scientific shrine " of the greatest interest to geologists is Rugbourne Farm, High Littleton, Somerset, where William Smith lodged from 1792–5 when surveying the local coal mines, for it was here that the fundamental principles of stratigraphy first became evident to him (cf. Cox and others, 1941, *Proc. Geol. Assoc.*, **52**, p. 21, pl. 2*a*). Visitors to High Littleton have had difficulty in locating this farm, and have found local residents woefully ignorant of the work of William Smith and of his connection with their village. It is, therefore, pleasing to record that, thanks to the initiative and persistence of Mr. J. B. Jones, of Swindon, and the action of the Clutton Rural District Council, a memorial signpost described by Mr. Jones as a substantial erection which does the local Council credit, has now been placed at the beginning of the bridle-path leading to Rugbourne. It reads : " To Rugbourne Farm/where William Smith, ' Father of/English Geology ' lodged, 1792–1795."

L. R. COX.

BRITISH MUSEUM (NATURAL HISTORY),
LONDON, S.W. 7.
16th October, 1951.

SILICATE ANALYSIS

SIR,—I much appreciate the thoroughness of the kindly review of the 2nd Edition of my " Silicate Analysis " in your September–October number, but in the concluding paragraph attention is drawn to a supposed error in the result of the silica determination in Appendix B, an error which is said also to have appeared in the 1st Edition. As, however, the reviewer himself has erred in this instance, a few words of explanation seem desirable.

The ignited residue remaining after the expulsion of silica by means of hydrofluoric acid consists of any R_2O_3 oxides contaminating the silica, plus the non-volatile residue invariably left by the hydrofluoric acid and which in the case of the ordinary " redistilled " grade is often considerable. The blank for the HF is accordingly *added* to the SiO_2 figure and *deducted* from that of the R_2O_3 (the R_2O_3 being subsequently ignited and weighed on top of the residue in the same crucible). The correct figure for SiO_2 therefore is 51·44 as given in Appendix B in both editions. In Appendix C, where the final results of the analysis are tabulated, a misprint causes the silica to appear as 51·47 and this may have contributed to the reviewer's misapprehension.

A. W. GROVES.

MINERAL RESOURCES DIVISION,
COLONIAL GEOLOGICAL SURVEYS,
IMPERIAL INSTITUTE, LONDON, S.W. 7.
16th October, 1951.

(I stated in my review that the value for SiO_2 given as 51·44 per cent presumably included the blank for HF. I still regard it as an error to place this value opposite a determination which gives 51·14 per cent. The final value for SiO_2 should appear lower on the page, *after* the value of the blank for HF has been given, and not before.—S. R. N.)

OLD RED SANDSTONE OF PORTSALON

SIR,—Mr. Bishopp's note on p. 371 of the current volume suggests a Torridonian age for the red sandstone with conglomerates south of Portsalon.

The sandstones of this outcrop are tilted to the north in a " faulted " attitude, but it is believed that the fault is either completely older than the deposit or that only a slight amount of movement has followed the deposition of the red sandstones. If the northern edge of the outcrop of the Knockalla quartzites is examined carefully it can be seen, on many small, steeply inclined

exposures away from the shore, that sedimentary infiltration and a reddish stain have run along joint cavities in the quartzite. The sediment infiltration suggests deposition against a scarp, possibly a fault scarp, though no fault has been demonstrated. It is considered that most, if not all, of the dip of the conglomerates near the present shore is original.

The observation of the sediment infiltration was checked by Sir E. B. Bailey and he unhesitatingly accepted the sedimentary contact of the sandstone series against a cliff of the metamorphic quartzite formation.

The above supports the Geological Survey's date, which was based on the very " Old Red " look of the sediments.

GERALD ANDREW.

GEOLOGICAL SURVEY OF ANGLO-EGYPTIAN SUDAN,
KHARTOUM.
6th November, 1951.

DOUBT AND CERTAINTY IN SCIENCE

SIR,—Two leaders of palaeontological thought in Europe have this year published discussions of the problem of extinction of faunas. (Both works were reviewed in this Magazine, 1951, vol. lxxxviii, pp. 303 and 372). The two following extracts summarizing their conclusions make an interesting comparison and provide food for thought.

" These wholesale disappearances and the sweeping changes in the population of sea and land which result from them always correspond with important geological events. Regularly they accompany great transgressions or regressions of the sea, tectonic upheavals, or climatic changes ; in short, they coincide with the great geodynamic crises which periodically modified the face of the earth."—C. Arambourg, 1951, in *Paléontologie et Transformisme*, p. 97.

" The supposition that flourishing groups of cosmopolitan organisms could be annihilated by mountain-building or changes in the distribution of land and sea is untenable and must emphatically be rejected . . . It is therefore very short-sighted when, over and over again, organic evolution and above all extinction of faunas and floras is represented as closely dependent on geological events."—O. H. Schindewolf, 1951, *Grundlagen und Methoden der paläontologischen Chronologie*, pp. 119, 121.

Both pronouncements are supported by an impressive array of facts.

W. J. ARKELL.

THE SEDGWICK MUSEUM,
CAMBRIDGE.
19th November, 1951.

REVIEWS

PROCEEDINGS OF THE FOURTH EMPIRE MINING AND METALLURGICAL CONGRESS, 1949. Edited by F. HIGHAM. 1,139 pp. Published in two Parts at the offices of the Congress, London, 1950. Price 40*s*., or separately at 20*s*. each Part.

Some forty papers covering a wide range of topics were introduced during the course of the seven technical sessions comprising the main proceedings of the Fourth Empire Mining and Metallurgical Congress held in Great Britain in 1949. In detail, the sessions were concerned with (i) Empire mineral resources, (ii) modern prospecting methods, (iii) the effect of heat and humidity on workers in deep mines and metallurgical industries, (iv) drilling for petroleum, (v) the characteristics and resources of Empire coals and coal mining practice in Great Britain, (vi) mineral dressing, and (vii) mining and metallurgical industries.

Part One of the published *Proceedings* contains the papers and discussions of sessions (i) to (iv); Part Two gives the remaining sessions and three evening lectures. The latter deal respectively with metallurgical and mining problems in atomic energy, modern theory of metals and alloys, and briefly with the social impact of mineral discoveries.

Of particular interest to the geologist are the thirteen papers of the sessions concerned with Empire mineral resources and modern prospecting methods, which with their discussions comprise more than half of Part One of the *Proceedings*. The first session reviews the mineral position in each of the Dominions and Colonies, illustrated by well-produced folding maps showing the location of mineral deposits in several of the territories concerned. The nine papers on this subject contain useful statistics and other data. Their value as references, however, would have been enhanced had they included bibliographies as complete as that listing 152 publications which accompanies the resume of Empire coal resources in Part Two of the *Proceedings*.

The opening paper in the session on modern prospecting methods discusses the use of aerial photography in mineral exploration and the techniques of aerogeology. Several illustrated examples of geological reconnaissance mapping from air photographs are included in the text. Then follow three papers summarizing the application of geological, geophysical, and other prospecting techniques in South Africa, Australia, and Canada respectively. Each stresses integration of the various methods and together give a clear picture of development and progress in scientific mineral exploration.

J. S. W.

OPTICAL CRYSTALLOGRAPHY. By E. E. WAHLSTROM. Second edition. John Wiley and Sons (London: Chapman and Hall), 1951. pp. vii + 247, 217 figs. Price 36*s*.

This excellent little volume is a revised and expanded form of the first edition, which was published in 1943. The popularity of the first edition can largely be attributed to the many text-figures. The second edition is even more profusely illustrated, and about seventy illustrations of the first edition have been redrawn. The text-figures giving a three-dimensional representation of the optical indictrax, formation of interference colours and interference figures, optic orientation and dispersion are highly commendable. Another feature of great value is the conciseness of the book; although it embraces only 247 pages, it covers essentially the same topics as the standard textbook by Rosenbusch-Wulfing.

The general organization of the second edition remains the same as in the first. Many chapters have been revised, some sections rewritten. An appendix dealing with the Universal Stage has been added. The list of references has been brought up to date.

The book is clearly and competently written, the text-figures are well presented. The volume will undoubtedly find its way into the classrooms of many colleges and universities.

G. M. F.

THE GEOLOGY AND MINERAL RESOURCES OF THE FRASER'S HILL AREA, SELANGOR, PERAK, AND PAHANG, FEDERATION OF MALAYA, WITH AN ACCOUNT OF THE MINERAL RESOURCES. By Dr. F. W. ROE. pp. ix + 138, with coloured map. Geol. Survey (Federation of Malaya) Memoir 5. 1951. Price 6 dollars (Straits).

Most of the field work for this Memoir was completed by Dr. Roe prior to the occupation of Malaya by the Japanese, but much of the mapping had to be repeated after World War II because the geological map and his notes were lost. It was not until after he became Director of the new Geological Survey Department of the British Territories in Borneo that the volume was finally prepared and published.

It is a most valuable memoir, giving a clear and concise account of the geology and mineral resources of an area of just over 300 square miles in one of the most important tin-mining districts of Malaya, the chief tin-producing country of the world. It is thus not surprising that the economic aspects form so prominent a part of a volume which, nevertheless, contains a considerable amount of new information concerning the distribution and classification of the sedimentary rocks which cover about half the area, the Pahang Volcanic Rocks, which occur in one small isolated part, and the extensive granite and granitic rocks which are genetically intimately associated with the tin mineralization.

In this part of Malaya, much of the cassiterite has been won from the granite foot-hills and the Main Range granite where the weathered outcrops of innumerable narrow tin-veins ramifying through the granite have been removed by ground-sluicing. To the Chinese miner this was the cheapest form of "lode-mining" (for it was lode-mining made easy by natural weathering), but to the Government it was the most expensive because it resulted in the burying of the old town of Kuala Kabu to the house-tops, in wide deviations of the main road and railway, and the building of new bridges, etc.

Such ground-sluicing has been prohibited since 1933. The author points out that the method uncovered lodes in the underlying hard rock, but that it was exceptional to find these rich and wide enough to be worked other than where two or more veins coalesced or intersected.

He gives an interesting account of the wide and rich lodes that were worked intermittently from 1910 to 1938, at Gunong Bakau, at a height of over 4,000 feet, and refers to previous publications on this and other tin occurrences in the area. He describes localities where unworked alluvial deposits may possibly be found, and convincingly advocates that when the alluvials in the low-lying areas have been worked to bedrock the barren ground should be used as dumping sites to allow resumption of ground-sluicing at higher levels. The coloured geological map, and the plans and sections illustrating the memoir, will become increasingly valuable as the tin resources of the world become more limited.

W. R. J.

PRACTICAL OIL GEOLOGY. By DORSEY HAGER. 6th Edition. McGraw-Hill Book Company, New York, 1951. pp. xxi + 589, with 227 figs. Price 47*s*.

The first edition of Dorsey Hager's book was published in 1915. Since that time there have been rapid advances in the development of techniques in petroleum geology and the present-day approach to the practical problems of this branch of economic geology is vastly different. Over the past three decades a considerable literature has grown up dealing with the various aspects of petroleum geology, and in consequence only the essentials can be considered in any book which attempts to deal with all the current problems.

In this revised edition, in which additional material such as structural geology, well-logging, and sampling has been included, the author has produced a compact treatment of the essentials of petroleum geology. As in previous editions, the book has been designed primarily for those engaged in the oil industry, especially in the U.S.A., and it assumes that the reader has no knowledge of geology. Thus the book discusses the fundamental principles of geology and then applies these principles to practical problems in oil geology. Many of the aspects of the subject which are discussed, such as drilling and production problems, would more properly be considered at the present time to be within the sphere of the drilling or reservoir engineer, but the treatment throughout is, rightly, from the point of view of the geologist rather than the engineer.

C. A. F.

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